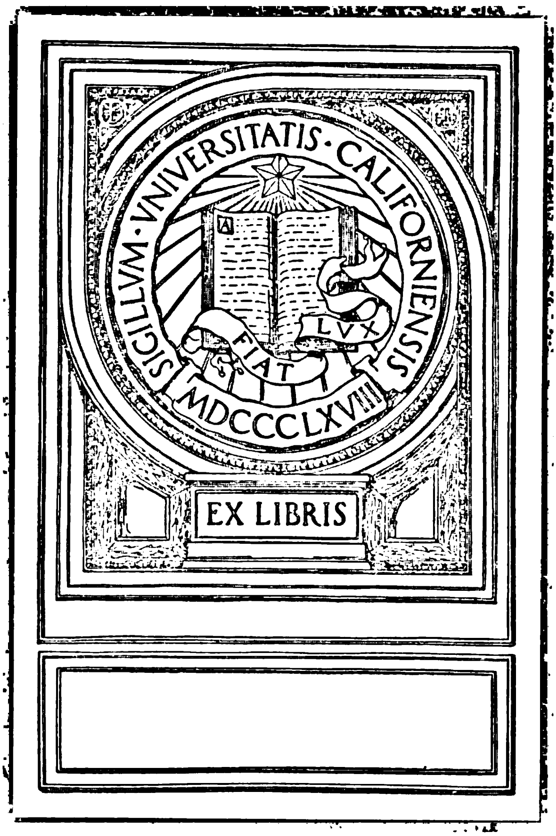
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ELECTRIC WELDING

A COMPREHENSIVE TREATISE ON THE PRACTICE OF THE VARIOUS RESISTANCE AND ARC WELDING PROCESSES, COVERING DESCRIPTIONS OF THE MACHINES AND APPARATUS USED AND THE APPLICATIONS BOTH IN MANUFACTURING AND REPAIR WORK

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PREFACE

Electric welding has become so important an art in the mechanical industries that a comprehensive treatise on this subject covering both the resistance and the arc welding processes is needed in the trade. A special study of the subject has, therefore, been made by the authors of this work, who have been assisted in their work by the experts in resistance and arc welding of some of the most prominent concerns in the United States engaged in this line of work. Credit is especially due the C. & C. Electric & Mfg. Co., the General Electric Co., the Lincoln Electric Co., the Thomson Electric Welding Co., the Westinghouse Electric & Manufacturing Co., and the Wilson Welder & Metals Co. for the coöperation and assistance which they have rendered in supplying information in connection with this undertaking. Consultations with the experts of these companies have made it possible to obtain thoroughly up-to-date information embodying the latest developments and discoveries in the art, and it is believed that, for this reason, the book will prove especially useful to those who are already employing electric welding equipment or who are contemplating its use, as well as to the students of the subject who desire to obtain authoritative information on the electric welding processes. Credit is also due Mr. Alan M. Bennett, whose treatise on Arc Welding, written for Machinery, has been freely consulted and employed in the writing of the chapter on Arc Welding.

The Authors.

New York, *February*, 1918.

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ELECTRIC WELDING

INTRODUCTION

ELECTRIC WELDING PROCESSES

THE application of electrical energy has occupied the minds of some of the foremost inventors during the past forty years, and the development that has taken place in this branch of engineering has been remarkably rapid. Some of the greatest manufacturing industries in the world have been built up on the basis of the inventions made in the electrical field; and, furthermore, the practical applications and uses of the electric current are by no means limited to the fields it has already invaded. It is not only likely, but quite certain, that in the future the service rendered by the electric current will be still more extensively employed. One of the many uses of electric energy in the metal working trades is found in its application to electric welding. Although the electric welding process passed out of the experimental and into the practical stage many years ago, the subject is one that is still rather vague in the minds of most mechanics. Electric welding, however, plays an important part in the industries at the present time, and several large companies have been formed that devote their entire attention to the manufacture of articles in the making of which electric welding forms one of the principal processes. Without the methods of electric welding, many of these products would have to be manufactured in an entirely different way and, in many cases, at a greatly increased cost. In these introductory paragraphs, the different processes of electric welding will be briefly reviewed, so as to provide a comprehensive review of the whole subject; in subsequent chapters, each of the more important welding systems will be taken up in detail, and the

apparatus and the methods of doing the work will be shown and described.

Different Systems of Electric Welding. — The principle of electric welding is simple; the parts that are to be welded together are heated to a welding temperature by means of an electric current. There are two ways in which the electric current can be utilized for heating to a welding temperature, and, according to the methods used, two main processes or systems of electric welding may be distinguished — the electric *resistance-welding* process, and the electric *arc-welding* process. In the former — the resistance-welding process — the parts to be welded are brought to a welding heat by the passage through them of an electric current of such voltage and amperage that the resistance to the flow of the current is great enough to produce sufficient heat at the points or surfaces to be welded, so that, when the parts are brought together by a slight pressure, they will be joined by the fusing of the metal — that is, by welding. In the latter system — the arc-welding method — an electric arc is drawn between two electrodes, or between the work and one electrode. This arc is brought into such a position relative to the work that the heat from the arc melts the metal to be welded, and enables the parts to be united. There are various modifications of this latter process, but, in principle, the above description is correct.

The resistance process of electric welding, in turn, may be divided into two specific processes, differing from each other in some important details. The process generally known as the *resistance* or *incandescent* welding process was developed by Elihu Thomson, in 1886, and is, therefore, also generally known by the name of the inventor as the Thomson process. The *percussion* electric welding process, which was developed by L. W. Chubb at the Westinghouse Electric & Manufacturing Co., is also in principle a resistance-welding process.

There are at least four distinct methods under the head of electric arc-welding processes. These methods are named after the men who are generally credited with their development, and are known, respectively, as the *Zerener* process, the *Bernardos*

process, the *Slavianoff* process, and the *Strohmenger-Slaughter* process. Another method known as the "voltex" process may be considered as a development and improvement on the Zerener process. The Slavianoff process is sometimes not considered as a distinct method, but merely as a development of the Bernardos process.

There is still another process which is frequently classified as an electric welding process — the LaGrange-Hoho method — also known as the "water-pail forge." This method differs from the regular resistance or arc-welding processes in that it is simply a heating process replacing the blacksmith's forge, the welding itself being accomplished by hammering on an anvil, as in ordinary forge welding.

Resistance Welding. — In the resistance, incandescent or Thomson electric welding process, the metals to be welded are brought into intimate contact by being held closely together by metal clamps actuated by springs or levers, so as to permit a constant pressure on the parts to be welded, even after the metal at the welding surfaces becomes plastic. The parts to be welded form an electric circuit, and the resistance at the point of contact between the two surfaces to be welded produces a welding temperature in a very short time; the metal parts are then forced together and thus welded. A distinct feature of the resistance welding process is that the interior of the metal is raised to a welding temperature before the surface reaches that heat, so that, if the exterior surface is welded, it is certain that the interior is also properly welded, since it is at a somewhat higher heat. When work is heated for welding in a forge, the opposite conditions take place. A perfect weld may be indicated on the surface, but this weld may cover an imperfect joint inside.

Welding machines built in many different designs for handling various classes of work are used for electric resistance welding. These machines consist principally of a transformer for changing the current to a low voltage and a high amperage, which is required in order to produce the necessary resistance; clamps for holding the work, which also transmit the current to the

work and which are generally known as "electrodes;" means for forcing these clamps or electrodes together; and electrical control for regulating the flow of the current in accordance with the area of the section to be welded. Single-phase alternating current is used, and the voltage of the generated current is generally 220 or 440, with a frequency of 60 cycles. When multi-phase current is employed, the welding machine can be connected with one phase of the system. Higher voltages and lower frequency than mentioned above may also be employed.

The resistance welding process is employed for regular butt- and lap-welding, as well as for a number of special welding methods that have been developed in connection with electric welding, known as "spot" welding, "point" or "projection" welding, and "ridge" welding. Work may also be heated in electric welding machines for upsetting to form collars on the ends of pieces of metal, heating blanks for forging or bending, as well as for heating work for hardening or annealing. The resistance process is especially adapted for duplicate work and is extensively used in such industries as automobile and bicycle manufacture, small-tool manufacture, where the cutting parts of tools are welded to the shanks, and in many other instances. Generally speaking, the resistance process is more applicable to manufacturing work than to repair work, and the process is not applicable to the repair of broken or defective castings, unless these are of extremely simple forms. In cases of this kind, the arc-welding processes are employed.

The advantages claimed for the resistance welding process are briefly: A homogeneous weld is obtained; finished or nearly finished work may be welded without damage to the finish; the process is rapid; impurities are forced out of the joint; the cost of labor is reduced; and the welding operation is in plain view as it proceeds, so that defective welds may be easily prevented.

Percussion Electric Welding. — In the percussion electric welding process, the parts to be welded are heated instantly by the sudden discharge of a heavy electric current from a condenser; at the very moment when the current is discharged

from the condenser, the two parts to be welded are forced together with a rapid blow. The sudden rush of current momentarily melts the portions of the work that are to be joined, and by forcing them together at that moment, a good weld is secured. The process is of recent development and has so far been applied mainly to the welding of wires of the same or dissimilar metals, and to the welding of the end of a wire to another object of larger dimensions. The process will probably find many other applications in the future.

Zerener Arc-welding Process. — In the Zerener process, two carbon electrodes, so arranged in a holder that they form a V, are employed. An arc is drawn between the carbon electrodes and this arc is caused to impinge upon the metal surfaces to be welded by being so located in relation to a powerful electromagnet that the arc is forced toward the work. This causes the arc to act in a manner similar to the flame of an oxy-acetylene torch. This welding system, also commonly known as the *electric blow-pipe* method, on account of the peculiarity of the impinging arc, was invented by Dr. Zerener, of Berlin, Germany, some twenty years ago. In this case, no current passes through the work. The Zerener system, as well as all the arc-welding systems, is based upon the fact that when two rods of carbon or other electrodes connected to the poles of a generator, so that current flows through them, are brought into contact, a flame will play between them, this flame being known as an electric *arc*. The size of this flame or arc may be varied by increasing the gap or distance between the ends of the carbon electrodes, by increasing or decreasing the amount of current passing through the electrodes, or by placing varying resistance in the circuit. The Zerener method is used, to a limited extent, for comparatively small work on steel and brass, and for welding small corners in tubes and tanks. The process, however, is inefficient and complicated, and requires great skill to properly apply. Hence, it is not used as extensively as the Bernardos and the Slavianoff arc-welding methods.

In a development of the Zerener arc-welding process known as the *voltex* process, the carbon electrodes contain a small

percentage of metallic oxide which is converted into a metallic form and then vaporized. The metallic oxide used is frequently oxide of iron. The metallic vapor created by this arrangement increases the size of the arc and minimizes or prevents the carburization of the work by the carbon of the electrodes at the welding point, which is one of the difficulties met with in the regular Zerener arc-welding process.

Bernardos Arc-welding Process. — The Bernardos electric arc-welding process is, perhaps, the best known of the arc-welding methods and, until recently, was the most extensively used. It is specially adapted to large and heavy work. In this process, the arc is drawn between the metal of the work to be welded and a single carbon or graphite electrode. The process is, therefore, commonly known as the *carbon electrode* welding process. It is evident that the metal to be welded forms one electrode and the carbon the other electrode for the circuit. The arc is drawn by touching the electrode to the work and withdrawing it to the proper distance in a manner similar to that in which an arc lamp is lighted. The temperature of the arc is approximately 3500 degrees C. (6300 degrees F.), and the heat is confined to a comparatively small space directly in contact with the arc. The use of a small electrode with low amperage permits comparatively light material to be welded, but the process is generally used with large electrodes and heavy currents for heavy work.

In the early development of this process, it was first attempted to use the carbon electrode as the positive terminal and the work as the negative terminal. These attempts, however, were unsuccessful, because part of the carbon from the electrode was carried into the work, making it very hard and, therefore, difficult to subsequently machine. It is, therefore, considered advisable always to connect the work to the positive side of the circuit and the carbon electrode to the negative. By this method, also, the greater portion of the heat of the arc is concentrated at the work, which is the positive terminal. The rod of carbon which forms the negative electrode varies generally in size from $\frac{3}{16}$ to $1\frac{1}{2}$ inch in diameter, according to the size

of the work to be welded. It is held in an insulated holder, which the workman holds in his hand, striking the arc by placing the carbon in contact with the work and quickly withdrawing it a distance from the metal. The operator then manipulates the arc so as to spread it, and heats the work at or near the point to be welded with what is called a "soaking" heat. The pieces of metal to be welded are melted on their faces together with a small iron rod which acts as a solder and flows in between the two surfaces to be joined. The work is often hammered after the weld has been made by the arc. Screens with colored glass windows and heavy gloves must be used to protect the eyes and skin of the workmen from the effects of the violet rays of the arc.

The Bernardos system when properly adapted to the work to be done is practical, simple, and efficient. Direct current is used. The quantity of current, depending upon the thickness to be welded, generally ranges from 200 to 500 amperes.

Slavianoff Arc-welding Process. — The Slavianoff electric arc-welding process is also commonly known as the *metallic* arc-welding process, because, in this case, a metal electrode is used instead of the carbon electrode. The objects of using a metal electrode are to prevent the introduction of carbon in the weld, to obtain a stronger weld, and to make vertical and overhead welding possible. The arc is drawn by touching the work with the metal electrode and drawing it away in the same manner as in the Bernardos process. No metal rod to act as a solder is required, however, as the metal electrode itself accomplishes this purpose by gradually melting away and entering the weld. The Slavianoff process produces a softer weld than the Bernardos process, because of the freedom from extraneous carbon in the weld. The arc is smaller than in the Bernardos process and, for that reason, the process is slower, but this is of less importance on small work. As the arc itself will carry the metal from the electrode to the work, it is possible to use this method for welding on a vertical wall or overhead, and hence the process is largely used in overhead repair work, in fireboxes, for welding flues in locomotive boilers, and, in general, when

repairs must be made in place. It is also largely used for welding steel plate in the manufacture of tanks, etc.

Strohmenger-Slaughter Arc-welding Process. — In the Strohmenger-Slaughter electric arc-welding process, the parts to be welded together are placed in the required position and an electrode, consisting of a soft iron rod covered all over, except at the extreme ends, with a flux suitable for the metal to be welded, and which also serves as an insulator, is laid upon and along the welding line. The work acts as one electrode, the same as in the Bernardos process. The work and one end of the electrode are brought into contact and an arc is thereby struck. This causes the electrode to melt, the weld being coated with the flux at the same time, thus preventing oxidation. The process is claimed to be successful in the welding of rails and for filling up worn places, but it is not so generally used as the other systems. In this process, either direct or alternating current may be used, but alternating current is preferred. Successful welding has been carried out with 85 volts direct current and 220 volts alternating current.

LaGrange-Hoho Electric Heating Process. — The LaGrange-Hoho electric welding process is, strictly speaking, not an electric welding process at all, but merely an electric method of heating the metal to a welding temperature. The method, sometimes referred to as the "water-pail forge," makes use of a wooden tank filled with a suitable fluid in which the positive electrode of the electric circuit is placed. A negative electrode is connected to the metal to be heated and this metal is then immersed in the fluid until it reaches a welding temperature. It is then removed and the actual forging or welding is carried out under a hammer or at the anvil in the usual manner.

Earliest Use of Arc Welding. — Arc welding appears to have been first used in 1881 by de Meritens for welding together parts of storage-battery plates. In this case, the work was connected to the positive pole of the current supply and a carbon electrode was used. The heat generated by the arc fused the lead of the storage-battery plate, the various parts of which were thus united or welded.

CHAPTER I

ELECTRIC RESISTANCE BUTT-WELDING

The principle of electric welding is extremely simple. An electric current of low voltage and comparatively high amperage is employed to fuse or soften the metal at the point of contact, and at the same time pressure is applied to force the parts to be welded together. The process is based on the well-known principle that a poor conductor of electricity offers so much resistance to the flow of an electric current that it will heat, the degree of heat depending upon the volume of current and the resistance of the conductor. In the electric-welding machine, a copper conductor carries the current with very little resistance to the work, but as soon as a piece of iron or other metal is placed in the circuit, it immediately becomes heated. If the volume of current or the amperage is large, and the iron conductor much smaller in cross-sectional area than the copper, the iron will quickly become hot enough to melt. This principle is well illustrated in an incandescent lamp; the copper wires leading to the lamp are good conductors of the electric current, and remain cool, whereas the carbon filament is a poor conductor and becomes so hot that it reaches a state of incandescence.

The pieces to be welded together in an electric welding machine, when clamped in position, complete an electric circuit which is inadequate to carry the heavy current passing through them without heating. As the heat of the metal increases, the resistance also increases, and the union or weld is thereby accelerated. As the temperature increases, however, the current volume usually decreases, a greater volume of current being used at the beginning than at the end of the heating. The heat is confined to the metal between the clamps or jaws, and a welding heat is reached so quickly that there is very little time

for the wasting of current by radiation or conduction. Therefore, practically all the heat is consumed in useful work, and the pieces, not having been heated except at the joint, are not distorted or discolored. The chief point that distinguishes electric resistance welding from all other welding processes is the fact that the heat is generated uniformly in the section being heated, that is, the heat is not applied to the exterior and conducted into the interior. The pieces being heated are in full view of the operator so that the action that takes place is always under observation. In this way, any trouble caused by uneven contact of the pieces, rust or scale, which will cause the pieces to heat unevenly with a tendency to burn at one or more points, can be instantly remedied. Varying temperatures can be obtained and retained for any length of time, and, as a rule, no flux is required.

Early Development of Electric Welding. — Although the first idea of the possibilities of joining metals by means of an electric current was conceived by Dr. Elihu Thomson early in 1877, it was several years before he did anything definite in regard to designing and building apparatus for this process. It was not until the plant of the Thomson-Houston Co. was removed from Philadelphia to New Britain, Conn., that an idea for a welding transformer was actually put into shape. This, however, was not put into practice until the manufacturing establishment previously mentioned was moved to Lynn, Mass., in the fall of 1883. In the time intervening between 1883 and 1885, Dr. Thomson started to make a welding apparatus in accordance with the plans of years before. At this time he had at his command an alternating-current dynamo which he had built, and he constructed a welding transformer with welding clamps or holders for the pieces to be welded. The original experiments were made in the winter of 1885 and 1886, and a larger machine was built shortly afterward.

The first device for electric welding, patented August 10, 1886, is shown in Fig. 1. The apparatus consisted of two arms or clamp-holding bars *A*, one of which was movable and swung on a joint *B*, which, when the arms were made from a metallic

substance, was insulated by interposing washers and a tube of insulating material, allowing a free movement of the arms but no passage of the current. Heavy cables *C*, which preferably were many times the section of the wire to be welded, connected the arms with the terminals of the apparatus producing the current. The work was held in place by means of clamps *D*, which held it firmly with its abutting ends projecting

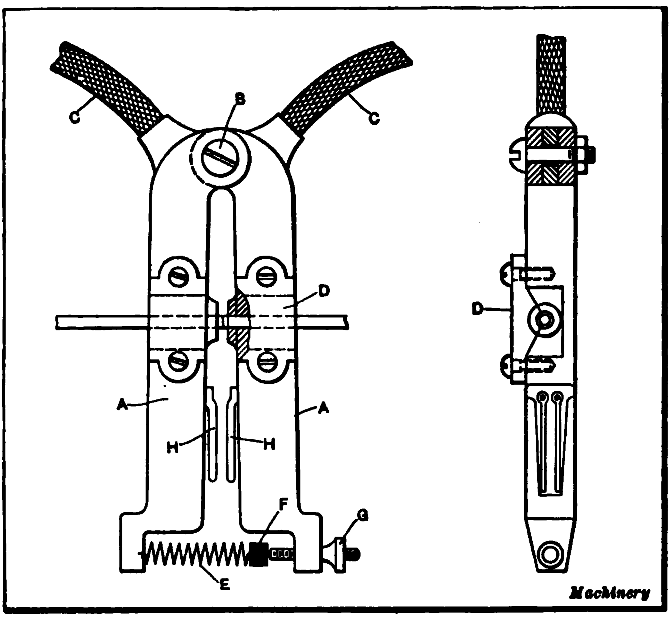


Fig. 1. First Practical Electric Welding Device patented by Dr. Elihu Thomson in 1886

as shown. The ends of these clamps were countersunk so as to leave a small portion in which the metal could upset. The mechanism for bringing the work into contact as it became heated consisted of the spring *E* insulated by a block or insulator *F*, which was acted upon by the screw *G*. Additional means, such as heavy copper contacts *H*, were sometimes provided, which automatically connected the arms for the passage of the electric current through them, after the joint between the two wires had been made, and in this way conducted the

heat through the body of metal in the arms and removed it from the metals in contact, to prevent excessive fusing.

There were several modifications of the arrangement shown in Fig. 1, one of which was to extend the arms *A* down slightly farther and form handles on the lower ends, so that the apparatus could be gripped by the hands and the rods brought into contact in this manner, instead of by spring action. Still another arrangement was to place the jaws or clamping arms in a horizontal position, extend one arm out farther than the other, and on this arm place a weight similar to that on a beam scale. In this way, the metals to be welded were brought into contact by means of the weight which was adjustable along one of the arms. An apparatus was also built in which the metals to be joined, instead of being held in a horizontal position, were located vertically, and the movable member was arranged in a slide, doing away with the swinging joints of the arms and bringing the metals into contact by means of gravity. With this apparatus, a great variety of trials were made, and some of the results of the work were put into actual use in the works of the Thomson-Houston Electric Co., Lynn, Mass. Wires were joined end to end, steel tools were welded, etc., and one of the earliest applications was the lengthening of auger bits. This was done by cutting off the square ends from the auger and substituting a steel bar of the desired length. Drills were lengthened in the same way, and innumerable demonstrations were made to show the application of electric welding to this kind of work.

Cooling the Clamping Jaws. — In the first device no means were provided for cooling the clamping jaws, which on heavy work, requiring heavy currents, soon became heated, unless they had sufficient mass to conduct away the heat. This, however, had already been provided for and was covered in another patent taken out at the same time as the previous one, the details of which are shown in Fig. 2. Water pipes *A* and *B* were arranged to pass through the clamping jaws *C* and *D*, this arrangement being advantageously used in welding large masses of metal or where the metal to be welded is a good con-

ductor of the electric current, such as copper. Where the pieces to be joined were of unequal size, a torch, as shown in the illustration, was brought into use, the flame being applied to the part having the larger section in order to compensate for the difference in heating. This modification of the apparatus was used for welding bars of unequal section, or T-welding, and similar work, which in apparatus of today is done without the torch, and is handled by using different arrangements of the clamping jaws or double transformers.

Controlling the Current. — A means of controlling the current passing through the electrical apparatus for welding was

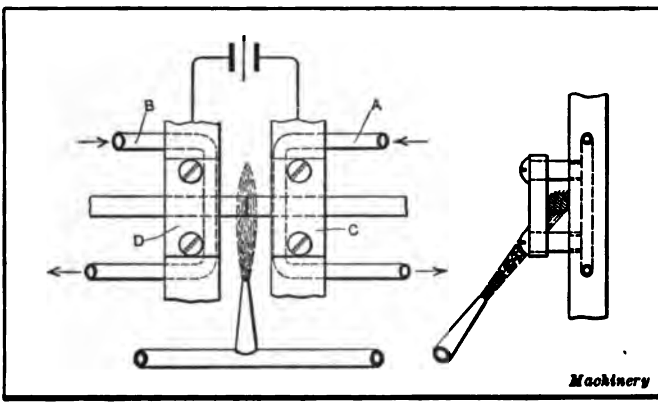


Fig. 2. First Device patented in connection with an Electric Welding Machine for Cooling Clamping Jaws

also patented in 1886, and is shown diagrammatically in Fig. 3. This device provides a means for regulating the electric current by means of an induction apparatus or transformer. In addition, this patent also covered improved methods of clamping the work. In Fig. 3, *A* and *B* are the wires which lead from the source of alternating-current supply to the coil of insulated wire *C* wound around a ring-shaped iron core *D*. The coil *C* had a number of turns depending upon the electromotive force and current that supplied it. The connection between *A*, *B*, and *C* was made so that a variable resistance *E* could be inserted in greater or less amount so as to vary the force of the primary

circuit current in the coil *C*. The switch *G* was arranged to permit breaking the circuit at will. Around the iron core *D* was wound a few turns of heavy copper cable *H*, giving an almost inappreciable electric resistance. The ends of this secondary coil were attached to each one of the clamp-bearing arms *I* which were also made of a good conducting metal. These were so placed and guided as to have only a slight move-

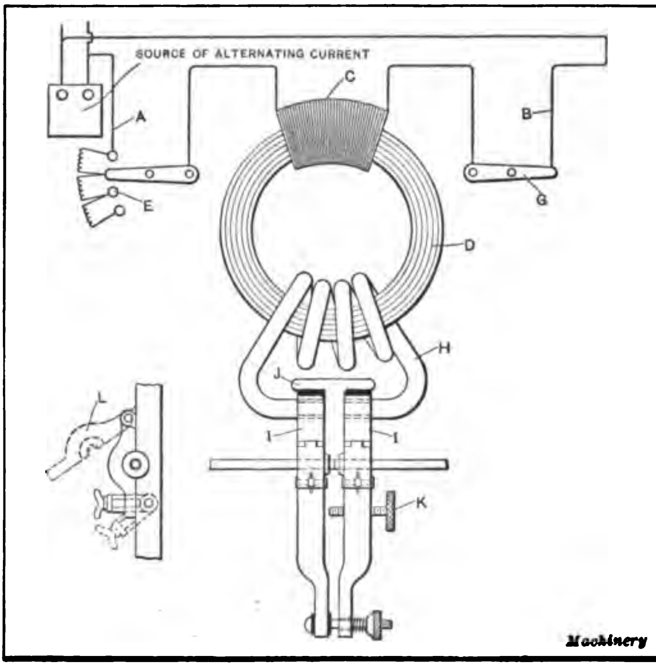


Fig. 3. Means for Controlling and Regulating Current, and Improved Method of clamping Work

ment toward and from each other. To provide for this, an insulated flexible plate *J* was used in conjunction with an insulated screw *K* which controlled the movement of the arms. A nut and compression spring shown at the lower end of the clamping jaws permitted the drawing of the arms together as the work approached the welding heat.

In order to manipulate the clamping jaws rapidly, they were made as shown to the left in the illustration. The jaws *L* were

hinged as shown, and arranged to be set or clamped by means of a movable clamping screw swinging in the frame. The dotted and full lines show the position of these parts relative to each other when clamped and released. The bore of the clamping jaws was made nearly equal to the dimensions of the bar to be clamped, and was countersunk on the inner surface to allow for the upsetting of the metal. The core and primary coil were made in several different arrangements, but the diagram shows the apparatus in its simplest form and of the type which was first adopted.

Slow Application of Electric Welding. — The applicability of electric welding to the metal-working industry was not realized as soon as its possibilities would seem to have merited, so that a considerable portion of the life of the patents previously described passed by without much attention being given to the process. Too conservative an attitude prevented, in many cases, the immediate use of this art. Perhaps the greatest help to the application of electrical processes generally, including electric welding, has been the great growth in recent years of stations for generating and transmitting electrical energy. Electric welding has now extended into many fields and given rise to special industries which are based upon it, so that, at the present time, this art is used in many of the important metal-working manufacturing plants.

When the art was first conceived, however, it was not quickly taken up, although after the first experiments practically no further investigations were needed. The process as originally applied and developed was carried on extensively without any appreciable change. There have, of course, been improved designs of apparatus and improved construction of welding transformers adapted to particular uses, but a great deal of this work was foreseen from the start, and in many cases was provided for. It may also be mentioned, as a matter of history, that, since the original patents of electric welding were taken out by Dr. Thomson, there have been a large number of patents — over 150 — taken out by the Thomson Electric Welding Co., under which they are now manufacturing their welding appa-

ratus. Patents have also been taken out by a number of other firms and men engaged in this industry, and, in fact, the patent records at the present time contain more literature on this subject than is available anywhere else.

Metals that can be Electrically Welded. — Practically all the metals can be electrically welded, as well as many of the alloys. A few metals can be welded electrically that are found impossible to weld satisfactorily by any other means. The metals that are most generally welded are aluminum, antimony, bismuth, cobalt, copper, gold, iron and steel, lead, manganese, nickel, platinum, silver, tin, and zinc. The alloys which can be welded are aluminum bronzes and brasses, and aluminum iron alloys, brasses and bronzes of practically all compositions, German silver, gold alloys, gun-metal, monel metal, silver alloys, solders, and type-metal. The following combinations of metals and alloys can be welded: Aluminum to copper and brass; brass to copper, German silver, machine steel, wrought iron, platinum, and tin; cast copper to brass, galvanized iron, wrought iron, and steel; wrought copper to brass, German silver, gold, and silver; German silver to brass, copper, gold, and wrought iron; gold to copper, German silver, platinum, and silver; wrought iron to brass, tool steel, and German silver; machine steel to brass, high-speed steel, nickel, nickel steel, platinum, tool steel, and wrought iron; tool steel to machine steel, platinum, and wrought iron; lead to tin; monel metal to brass, galvanized iron, and wrought iron; nickel to wrought iron; platinum to brass, gold, silver, and steel; silver to copper, gold, and platinum; tin to brass, lead, and zinc; and zinc to tin.

Many combinations not specified in the preceding paragraph can be welded, but require special apparatus for the purpose.

Cast iron cannot be commercially welded, except in small sections, as it is high in carbon and silicon, and passes suddenly from a crystalline to a fluid state when brought to a welding temperature. For welding wrought iron or steel, the temperature must be kept below the melting point, and consequently considerable pressure is required. High-carbon steel can be

welded, preferably with a borax flux, but must be annealed or, preferably, hammered after welding, to overcome the strain set up by applying the heat locally. Good results are difficult to obtain when the carbon runs as high as 0.75 per cent or above, and can only be obtained by an experienced operator. When the carbon content is below 0.25 per cent, the operator can always make a good weld. To weld high-carbon steel to low-carbon steel requires experience, and this process will be described later.

Nickel steel can be readily welded. Wrought iron can be welded to copper, but it is necessary to reduce the cross-section of the copper to equalize the heating. When welding copper to brass, the pressure must be less than when welding iron, but a greater quantity of current is required, because of the reduced resistance. The metal is allowed to actually fuse or melt at the weld, and the pressure should only be sufficient to force out the burnt metal. The fact that the burnt metal is forced out accounts for the good results obtained in welding these materials. The electric current, however, must be shut off at the instant that the ends of the metal begin to soften. This is done by an automatic switch which opens at a predetermined point, found by experimenting with the different diameters and alloys of metal. The sliding head of the machine is actuated by either springs or weights to force the heads together as soon as the metal softens, and this automatically operates the switch. As copper and brass are good conductors of electric currents, a large volume of current at low voltage is used, and the sliding heads are arranged to move with the least possible friction.

With metals such as lead, tin, and zinc, the degree of heat required does not produce light, and the progress of the heating cannot be watched by the eye as in the case of iron and steel. Therefore, the plasticity, softening or fusion is really the index of the heat which the abutted ends have acquired. If the precaution be taken to shape the ends of the sections properly before applying the current and pressure, the joining of lead pipes, end to end, can be easily accomplished. The abutting

ends should be beveled so as to expose a smaller section than that of the pipe in order to reduce the cross-section and facilitate quick heating.

Tin welds easily, as does zinc and even such brittle metals as antimony and bismuth. The welding of aluminum, however, is more difficult and requires special precautions. For this work, automatic welders are generally used, so that the time at which the current is shut off can be very closely regulated. Even magnesium, oxidizable as it is, is readily welded, because it melts before reaching the temperature at which it ignites.

Different Applications of Electric Welding. — In order to unite different-shaped pieces by electric welding machines, it is evident that various types of apparatus had to be devised to handle the work expeditiously and satisfactorily. The process of electric welding has, therefore, been divided into several distinct applications; *viz.*, butt-welding, in which the metals are placed end to end; T- and angle-welding, in which the metal takes the form of the letter T or L; cross-welding, in which the metal is placed in the form of a cross or X; lap-welding, in which the sheets of metal are overlapped and squeezed together; seam-welding, either by abutting or overlapping the edges of sheet metal; spot-welding, which instead of riveting metal together joins it by means of an electrically welded spot, one or more spots being welded at a time; point-welding, or projection-welding, the joining of metal surfaces by a raised point or projections in which the current is confined or concentrated and the welding takes place only at these points, this process usually being employed in the manufacture of sheet metal; ridge-welding, a slight modification of the point method, in which the current is concentrated by means of a ridge instead of a point, across which a weld is made; upsetting, which consists in heating work and then upsetting it to form collars or the like; heating blanks for forging, bending and working; heating for hardening and annealing; and percussion-welding, especially applicable to the joining of very small wires of the same or different metals.

Electric Welding Machine. — The electric welding machine, although made in several different types, is primarily a device for transforming an electric current from high to low voltage and carrying it to copper contact points or jaws. It consists essentially of a transformer, a clamping device, and a pressure device. Although it is possible to give the transformer a different location from that of the other two mechanical elements, it is rarely done, and most commercial welding machines embody all three elements in the same machine. There are, of course, many special departures from this general form. The mechanical and electrical control may be operated by hand or foot, semi-automatically or automatically. For welding small work, such as wire, spring pressure in forming the weld is usually employed, and the clamping is either by hand or by power. For metals like copper and brass, a weight pressure is usually best. For round and similar sections up to $\frac{3}{4}$ inch, hand pressure is usually employed. On larger sections, hydraulic pressure or pressure obtained through self-contained oil jacks is used.

The butt-welding machine derives its name from the operations performed by it. Two pieces of round, square, or rectangular-shaped stock are placed in the clamping jaws with only from $\frac{1}{8}$ to $\frac{1}{2}$ inch of metal extending beyond the jaws. The ends of the metal touch each other, and as soon as the electric current is turned on, the abutting ends immediately begin to heat. When the welding temperature is reached, the jaws are brought together by operating a lever, or other mechanical means, and the two ends of the partially molten metal are thus united. Electric welding machines are necessarily more or less special in the construction of their clamps and electrodes, no one machine being suitable for a great variety of sizes or forms of work. Some machines are entirely special and suitable only for the work for which they were built, some are semi-automatic in their operation, requiring the operator only to put in and take out the pieces, while other machines are entirely automatic, the clamping, pressure for welding, and controlling of the current being handled automatically. In

addition to butt-welding, several other operations such as T-welding, jump-welding, cross-welding and upsetting can be performed on a butt-welding machine by employing various arrangements of the clamping jaws.

Fig. 4 shows a simple form of machine for welding straight rods or tubes. The clamping dies *A* are fitted to the work they are to hold, and are mounted on the sliding supports *B* and B_1. The supports are mounted on guides shown at *C*.

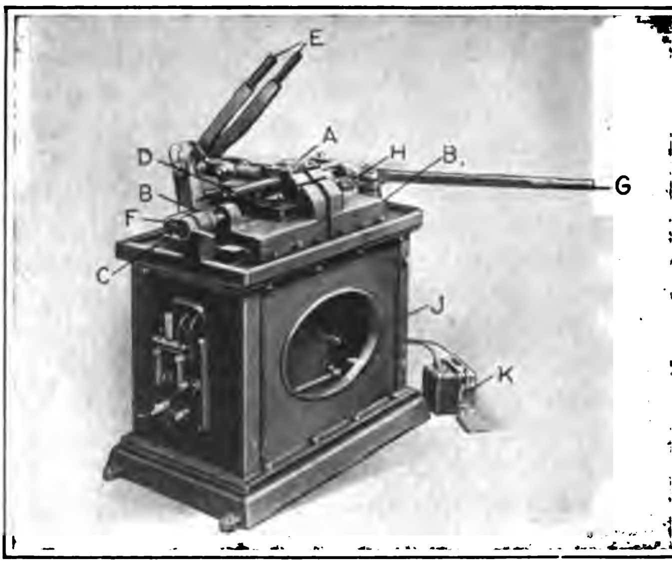


Fig. 4. Simple Form of Machine for Welding Straight Rods or Tubes

The clamping dies are operated to grip the stock *D* by means of the clamping levers *E*. The left-hand head *B* is stationary while welds are being made, but it can be adjusted by means of the shoulder-screw *F*. The compression toggle lever *G* is connected to the right-hand head B_1 by links as shown at *H*. The welding transformer *J* can be seen through the opening in the side plate of the machine. The foot switch for closing and opening the current through the primary coils of the transformer is shown at *K*.

Operation of an Electric Welding Machine. — The several steps in the operation of the machine when making a butt-weld are as follows: Two pieces of stock are clamped in the dies with the surfaces to be welded opposed and abutting, the dies being separated from each other a short distance to allow a converging motion for compressing the stock at the proper time. A switch connecting the primary coils of the welding transformer to the supply circuit, and which may be hand- or foot-operated, as convenience may dictate, is closed. The induced secondary current of the transformer now flows through the heavy flexible connecting leads, through the clamping supports and dies into the stock to be welded, and across the abutting surfaces. The junction of the welding stock is the point of highest electrical resistance in the entire transformer secondary circuit, which is made up of the secondary winding, connecting leads, clamping supports and dies, and the small projection of stock over each clamping die. The design of the transformer, secondary leads, clamping supports, dies, etc., makes their combined resistance very small as compared to the contact resistance at the point of weld. In conformity to the laws governing the heating of conductors carrying electric currents, practically all the heating will be confined to this point. In other words, nearly all the electrical energy taken from the supply circuit will be concentrated at this one point in the form of heat.

The secondary voltage of the transformer is so selected that the volume of secondary current forced through the junction of the two pieces of stock will produce a welding temperature at this point in a certain predetermined time. The actual secondary voltage required will depend upon the cross-section of the material to be welded, and whether the stock is iron, steel, brass, copper, or aluminum. The voltage varies between one and seven volts. A voltage regulator of the inductive or "choking" type is usually supplied with each welding machine. This regulator is an auxiliary piece of apparatus connected in circuit with the transformer primary coils, and by means of which the secondary voltage can be readily adjusted through

a wide range to afford the best operating conditions on varying kinds and sizes of stock.

At the instant a welding temperature has been reached, the switch is opened and the stock quickly compressed under heavy pressure to form the weld. A small amount of semi-fluid ma-

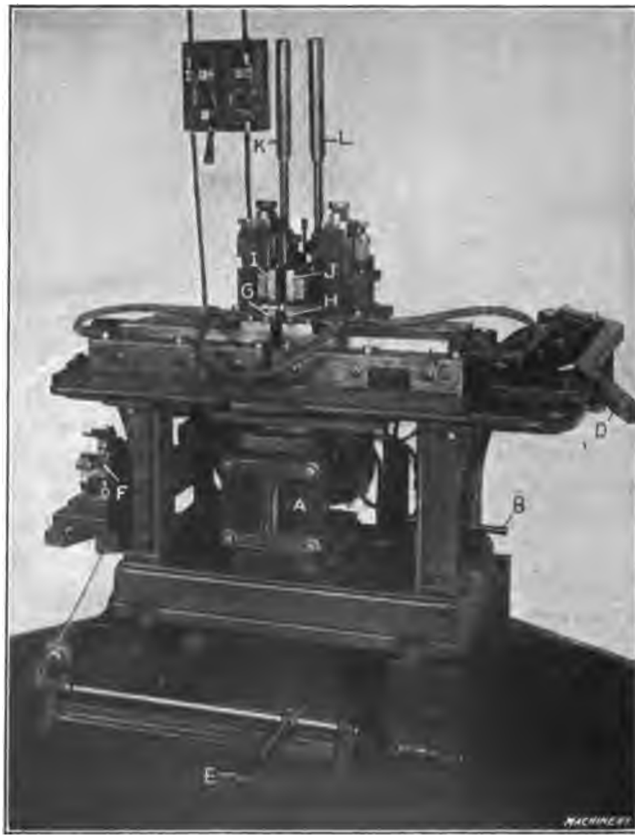


Fig. 5. One of the Latest Electric Butt-welding Machines built by the Thomson Electric Welding Co.

terial is displaced under the pressure and thrown out all around the stock at the point of weld in the form of a fin or burr. When necessary, this surplus metal can be removed by grinding or chipping, or it can be reduced under a power press to the stock dimensions.

Modern Design of Machine. — A typical butt-welding machine built by the Thomson Electric Welding Co., Lynn, Mass., is shown in Fig. 5. The transformer *A* is mounted on the base of the machine. The primary coils of the transformer are connected to an alternating-current supply which is regulated by the regulator *B*, and a secondary winding delivers a current at very low voltage (about three to five volts) but heavy amperage to the connecting leads running from the transformer to the clamping jaws. On account of the low voltage required, the secondary windings have a single turn extending through the laminated iron core. This secondary is built up of a large number of thin copper strips to afford the necessary flexibility to the motion of the clamping jaws.

The platen *C* moves on ball bearings and the pressure for bringing the two pieces of metal into contact when they have been heated is produced by the lever *D* shown at the right. The current is shut off by means of the brake switch operated by the treadle *E*, the switch *F* being located at the left-hand end of the machine. In order to keep the current-carrying members of the machine cool, water is circulated through the secondary terminals and electrodes. The two lower clamping jaws *G* and *H* are held rigidly to the platens of the machine, and when the machine has once been set for certain classes of work, the right-hand platen only is given a movement by means of the toggle-joint lever at the right. The two upper clamping jaws *I* and *J* are brought into and out of contact with the parts being welded by means of the levers *K* and *L*, which operate eccentrics in the head. This particular electric welding machine has a 30-kilowatt capacity, and is capable of handling work up to 1¼ inch round stock, or flat up to 4 inches wide. The time for welding stock which is the limit of the machine's capacity is 15 seconds, and the current consumption is 125 kilowatt-hours for 1000 welds. The weight of this machine is 2275 pounds.

Another type of butt-welding machine which incorporates the fundamental principles of the electric welding machine as first developed is shown in Fig. 6. The transformer *A* is carried

in the base of the machine. The primary coils of the transformer are connected to an alternating-current supply which is regulated by regulator *B*, and the secondary windings deliver a current of very low voltage but heavy current or amperage to the connecting leads running from the transformer to the clamping jaws. The two lower copper clamping jaws *a* are held stationary, whereas the upper jaws *b* for clamping the

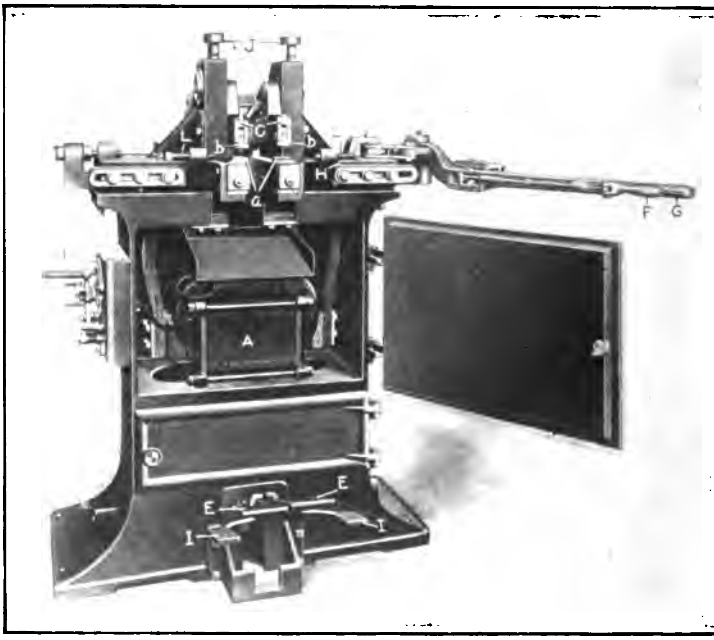


Fig. 6. Another Type of Butt-welding Machine

work are held in arms that are operated by the foot-treadles *E*. By operating the treadles, the two arms *C* are lowered, carrying the copper jaws that hold the work rigidly in position on the lower jaws. When this operation has been performed, the switch handle *F* is pressed, turning on the current, and the lever *G* is drawn in toward the center of the machine. This makes sliding head *H* travel in the same direction, and carries forward one part of the work that is to be welded. Handle *G* is not operated until the extended ends of the work to be welded

have reached a white heat or welding temperature. Then sufficient pressure is applied to the handle to upset the material and form a perfect weld. The arms carrying the top clamping jaws are released by means of releasing treadles *I*. The movement of the two arms *C* is controlled by eccentric adjusting screws *J* located in each head, as indicated.

The lower clamping jaws are cooled by a constant stream of water flowing through the pipes *H* and *I*, Fig. 7, which adds greatly to the increased life of the jaws. The head of the ma-

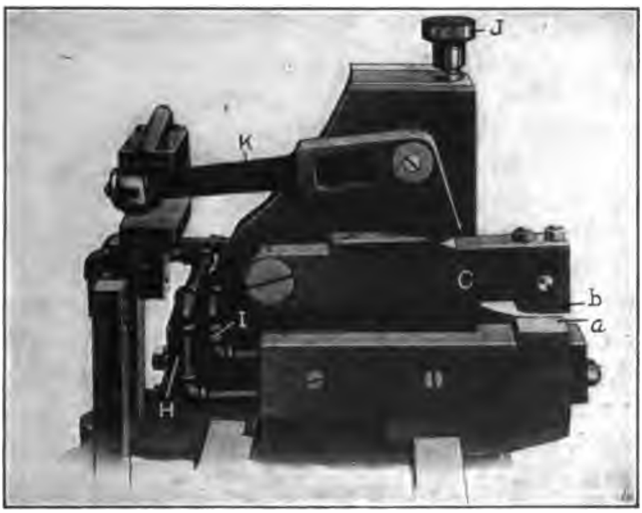


Fig. 7. Details of Clamping Jaws used on Machine shown in Fig. 6

chine carrying the different operating parts is an iron casting of massive construction. The cam lever *K* is a steel casting which rides upon a hardened steel shoe and reduces wear to a minimum. The small copper jaws held in the arms are the only parts that need to be replaced and are simply cut off from bars of copper stock. The stationary and movable heads are both provided with adjustable slides to take in various lengths of work, and, as shown in Fig. 6, carry backing-up stops *L* which serve to hold the work in its proper place and relieve the clamping jaws of considerable strain. All compression on the work

is taken on these stops instead of on the jaws themselves, and they enable the perfect duplication of lengths of work. The lever arms can be raised and lowered by means of the eccentric screws *J* shown at the top of the machine, to provide for different sizes of work. In changing over from one job to another, it is only necessary to change the clamping jaws, reset the stops and adjust the eccentric screws controlling the movement of the lever arms.

A number of special electric welding machines have also been built for welding spokes into hubs of agricultural machinery wheels, seam-welding steel tubing, welding railway rails in the streets, and making wire fencing and wire mesh for concrete reinforcing.

Preparing Work for Butt-welding. — For butt-welding, it is not necessary to prepare the metal, although, when rusty or covered with scale, the rust or scale should be removed from those parts of the pieces which are in contact with the jaws or each other sufficiently to allow good contact of clean metal. The work should preferably be cleaned with a sand-blast or emery cloth. Where there is a large amount of work to be welded, it is sometimes advisable to grind off the ends on an emery wheel to insure a good contact. Scaly forgings should be pickled, and this can be done at a slight cost. The pickling solution should be kept in a wooden, stone, or lead-lined tank, and is composed of five gallons of commercial sulphuric acid (oil of vitriol) added to 250 gallons of water. This solution requires only a few minutes to remove the scale. After dipping the work, wash off the acid in running water and dip the stock in limewater to neutralize any traces of acid; fifty pounds of unslaked lime to 150 gallons of water is about the right mixture. Both acid and lime solutions should be kept as near to the boiling point as possible, to obtain the best and quickest results. When the work is taken from the hot limewater, it dries very quickly, and a thin film of lime forms on it, which prevents rusting.

A good method of heating the acid solution is to run a coil of extra heavy lead pipe to the bottom of the tank and out at

the top for carrying steam. Cold acid solution may be used, but it takes much longer to remove the scale and also requires the use of a considerably greater quantity of acid. The cleaning of the work is an important point, as the best results can only be obtained when the stock is clean. The cleaner and better the stock, the easier it is to weld and the less current it takes; there is also less wear on the clamping jaws. The clamping jaws should be kept clean and firmly held in the holders. If dirt or scale is allowed to gather in the socket that holds the jaws, good contact cannot be made.

Another point in butt-welding is that pieces of similar metals should have their welding sections equal; that is, the two ends of the stock that come together must be of the same diameter or cross-sectional area. When a large piece is to be welded to a smaller piece, the end of the larger piece should be reduced to the section of the smaller for a length of from 1 to 2½ times the diameter. This applies to round stock, hexagonal stock, flat stock or tubing, and, in fact, any shape of work that it is intended to butt-weld. If this point is not observed, it is necessary to have a special arrangement of the dies and to preheat the piece which has the largest cross-sectional area in order to prevent burning the small piece while the large one is heating.

Projection of Work from Clamping Jaws. — In butt-welding, the work is allowed to project a certain distance out from the faces of the clamping jaws, and then, when it has become heated to the proper temperature, the jaws are forced together until, in some cases, they practically make contact. The amount of metal projecting is determined largely by the material to be welded and the type of weld desired. Fig. 8 shows the relative positions of the clamping jaws and the amount that the work should project from them for welding various materials.

Flash-weld. — At *A* is shown the amount that the stock should project from the clamping jaws when making a flash-weld on round or bar stock. This applies to the welding of wrought iron or steel. The space between the two jaws should

equal about 0.7 times the diameter of the work. The distance is never greater than the diameter of the stock for making a flash-weld. A flash-weld is generally used on stock that is wide and thin, and is sometimes advisable when the welding faces are not cut square and true. It is also used in welding tubing to tubing — in fact, in all cases where a small amount of stock is to be taken up in the weld, or when it is desired to shear or grind off the fin.

Upset Weld. — For making an upset weld, the stock should project from the jaws about the distance shown at *B* in Fig. 8.

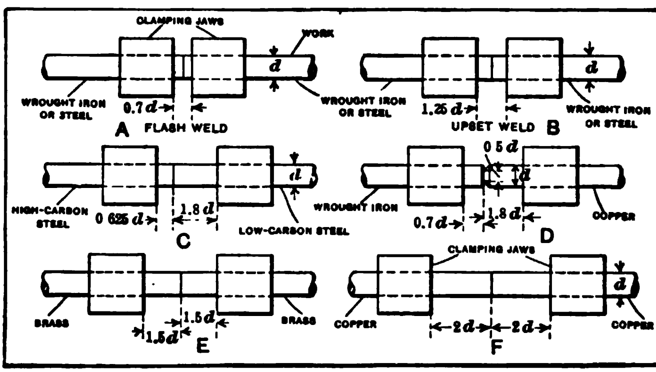


Fig. 8. Diagram showing Projection of Work from Clamping Jaws for Welding Different Kinds of Material and for Making Various Types of Welds

The amount of metal generally left extending from the jaws for making an upset weld in wrought iron or steel is about 1¼ times the diameter of the work. Upset welding is used in all cases where the weld is to be hammered, using the heat generated in welding; also, in some cases, on small rods or rings where it is not necessary to have a uniform thickness of stock. In welding materials such as copper, brass, tool steel, and other metals that are injured by high temperatures, they must be heated quickly and pressed together with sufficient force to push out all the burnt metal from the weld.

High-carbon to Low-carbon Steel. — When welding high-carbon steel to low-carbon steel, the stock should extend from the

jaws about as indicated at *C*, Fig. 8. The low-carbon stock should extend considerably farther than the high-carbon stock, the high-carbon stock generally extending about $\frac{5}{8}$ times the diameter of the work, and the low-carbon stock about 1.8 times the diameter of the stock. The reason for this is that the high-carbon stock offers much greater resistance to the passage of the electric current than the low-carbon stock, and hence heats up quicker.

Wrought Iron to Copper. — When welding wrought iron to copper, it is necessary to hold the work as shown at *D* in Fig. 8. The wrought iron should project from the jaws about 0.7 times the diameter of the work, and the copper about 1.8 times the diameter. The copper should preferably be reduced on the end to about 0.5 times the diameter of the bar. In this case, the copper is a better conductor of the electric current than the wrought iron and, consequently, does not heat up as quickly. The cross-section of the copper is, therefore, reduced to increase its resistance to the passage of the electric current and cause it to heat up quicker, or at about the same rate as the wrought iron.

Brass and Copper. — In welding one brass rod to another brass rod, the clamping jaws should be set apart about three times the diameter of the rod, as indicated at *E* in Fig. 8. The weld, however, only takes up a length equal to about the diameter of the bar, when the bar is over $\frac{1}{4}$ inch in diameter. In welding copper to copper, the work should project, as shown at *F* in Fig. 8, about four times the diameter of the rod. Here, also, only a length equal to about the diameter of the stock is utilized in making the weld, unless the stock is less than $\frac{1}{4}$ inch in diameter.

Various Arrangements of the Clamping Jaws. — In order to make different types of welds, various arrangements of the clamping jaws are necessary. Fig. 9 shows diagrammatically a number of different arrangements. The views shown are plan views, looking down on the top faces of the jaws. At *A* is shown the typical arrangement of the jaws for making an ordinary butt-welded joint, the work being clamped centrally be-

tween the upper and lower clamping jaws and projecting the required amount, as previously described, for various materials.

Sheet or flat stock is usually welded with a machine called a "spot-welder," provided with vertical clamping points or electrodes. This process will be fully described in a succeeding chapter. When the size and shape of the work will permit,

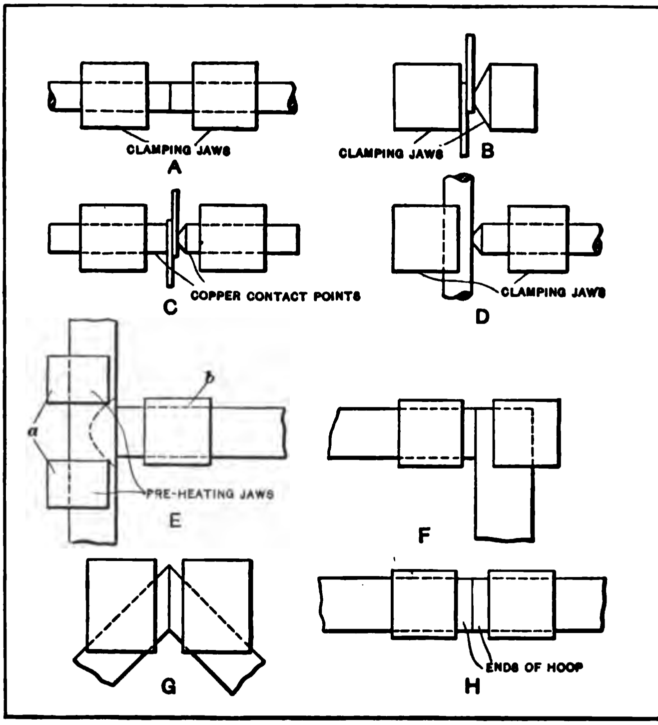


Fig. 9. Diagram illustrating Arrangement of Clamping Jaws for Performing Various Types of Welds

however, spot-welding operations can be accomplished on certain materials in a butt-welding machine by employing special arrangements of the clamping jaws as shown at *B* and *C* in Fig. 9. In practice, however, it is found that in some cases the necessary form of jaws on butt-welding machines renders them impractical on account of the impossibility of placing the work to be spot-welded in them. For spot-welding in an

electric butt-welding machine, the two upper clamping jaws are not used; and one of the lower jaws is pointed as shown at *B*, the other being provided with a flat face. The material having the least resistance to the electric current is placed in contact with the pointed jaw. This form of jaw is used in welding sheet steel, copper, and brass, but when galvanized iron is to be spot-welded, the faces of both clamping jaws must be pointed. The arrangement of the clamping jaws shown at *C* in Fig. 9 can also be used in an emergency for performing spot-welding operations on a butt-welding machine. Instead of using the jaws as electrodes, two round copper rods, as shown, are held in them, one of which is pointed for welding steel, brass, and copper; both of these rods must be pointed for welding galvanized iron.

For performing jump-welding operations on light stock, the arrangement shown at *D* in Fig. 9 is used. One piece of work is held parallel with the front faces of the clamping jaws as illustrated, and the other located at right angles to it. The piece of work located at right angles is generally pointed to reduce the cross-sectional area in order to enable it to heat up at the same time as the other piece, allowing a perfect junction to be made. This arrangement of the jaws is also used for the welding of tubing.

A rather unusual arrangement of the clamping jaws is shown at *E* in Fig. 9. This requires a specially constructed machine provided with two pairs of self-equalizing clamping jaws mounted on the left-hand head and insulated from each other. These two jaws are operated by one vertical lever and are used for gripping the upper part of the "T-bar" that is to be welded. The machine is provided with a double-throw switch operated by a foot-lever. The making of a tee-weld is accomplished by first heating the stock between the two auxiliary clamping jaws *a* for a distance of about one or two inches. When it is red-hot, the double-throw switch is turned to the left, which changes the flow of the current. The current then travels from the right-hand clamping jaw *b*, in which the lower part of the tee is held, to the left-hand preheating jaws. When

the lower part of the tee is brought into contact with the preheated bar and the current turned on, the two pieces quickly reach the welding temperature; a slight pull on the lever handle forces them together, and the job is done.

The diagram at *F*, Fig. 9, shows the arrangement of the clamping jaws and the work for forming a square-corner weld. One piece of work is held parallel with the traveling slide of the jaws, and the other at right angles to it. In this case, the sectional area of the two pieces is practically equal, so that no preheating of the bars is necessary. The flat bar in the right-hand jaw should project farther from the face of the jaw than the other piece, generally about twice the distance. At *G* another arrangement of the clamping jaws is shown for making a corner weld, but, in this case, the weld is made at an angle of about 45 degrees, making a miter joint. In this arrangement, the work is presented differently because of the angles on the work. The jaws are machined so that they act as a guide to present the two pieces at right angles to each other; the welding operation is a comparatively simple process, no preheating of the work being necessary.

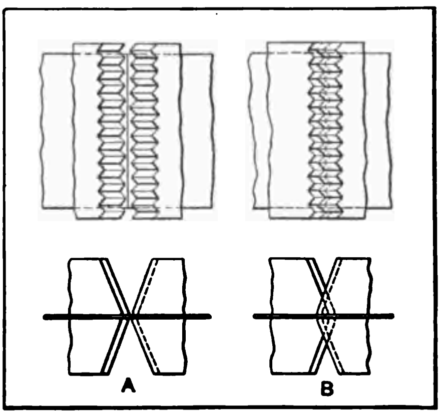


Fig. 10. Method of arranging Clamping Jaws for Butt-welding Thin Strip Stock

The butt-welding of hoops or rings, as shown at *H*, can also be done in a regular butt-welding machine in which the clamping jaws are so arranged as to allow the stock to be presented to them without coming in contact with the frame of the machine. The operation of welding is carried on in the same way as an ordinary butt-welding job.

A special arrangement of the clamping jaws (patented by the Thomson Electric Welding Co.) for butt-welding thin wide

strip stock in a butt-welding machine is shown in Fig. 10. This type of welding would be particularly difficult with clamping jaws of the ordinary shape, as it would be impossible to hold the thin stock close enough to the edge to keep the two edges in alignment and distribute the heat evenly. By constructing the jaws with toothed or intermeshing edges, as shown in Fig. 10, the stock can be supported practically to the edge, as shown at *A*, and still allow space for a burr to be formed at the weld when the jaws come together as shown at *B*.

Welding Pieces of Unequal Cross-sectional Area. — Fig. 11 shows a machine embodying the necessary apparatus for welding pieces of unequal cross-sectional area, which has been designed and patented by the Thomson Electric Welding Co. This is accomplished by using two transformers, one for heating the thick piece and the other for making the weld. In the illustration, the heating transformer is indicated at *A* and the welding transformer at *B*; *C* is the secondary circuit of the heating transformer; it consists of a metal yoke recessed to receive the primary coil *D*, and is bolted to the table top as shown. On one terminal is secured a slide *E* and on the other a slide *F*; these slides carry at their forward ends the lower jaws or work-holding members *G* and *H*. Mounted on slides *E* and *F*, but insulated from them, is an arm *I* on which the other work-holding members *J* and *K* are mounted. These upper clamping jaws are insulated and seated in the free end of the lever *L* which is pivoted to the arm *I*. This lever is depressed by the cam lever *M*.

The welding transformer has its secondary in the plane intersecting that of the heating transformer. It is secured to the table and has one of its terminals projecting and seated between the terminals of the heating transformer from which it is insulated. The other terminal of this secondary has mounted on it a slide *O* which carries at its forward end the lower jaw or work-holder *P*. The upper jaw or work-holder *Q* is carried on the end of lever *R*, which is pivoted to the curved arm *S*, mounted on the slide *O*. A cam lever *T* serves to depress the lever *R*, and a spring returns it substantially to its former

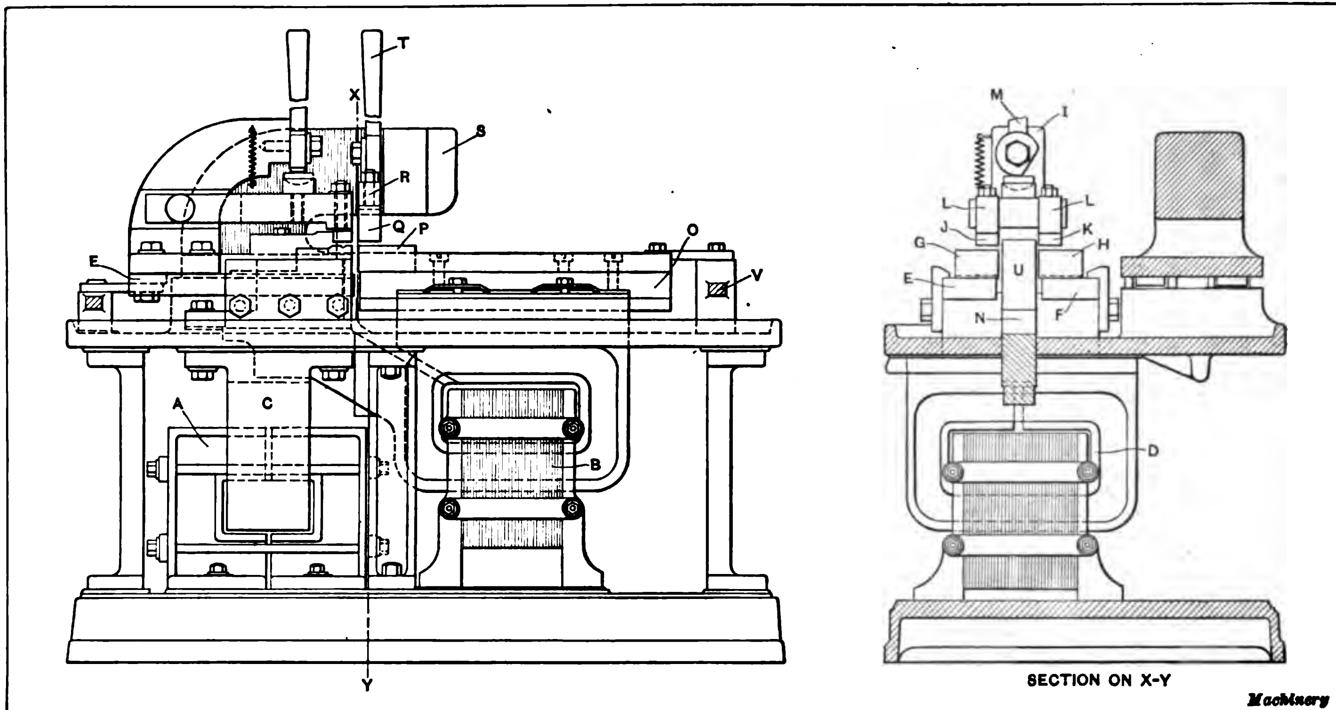


Fig. 11. Special Type of Electric Butt-welding Machine patented by the Thomson Electric Welding Co. for Welding Pieces of Unequal Cross-sectional Area. This Machine comprises Two Transformers

position. Anti-friction rollers are located between the base of the machine and the movable arm *S* to facilitate its movement. The work-holders are constructed so that the clamping bases may be readily removed, and are made as small as practicable, with sufficient contact area to concentrate the lines of force between the terminals of the secondary. The work-holders are also kept cool by circulating water through them. The primaries of the transformers *A* and *B* are connected to a source of electric current in parallel, and each is provided with a switch so that it can be operated independently.

In using this apparatus for welding a thin piece to the side of a thick piece, the latter is clamped between the jaws *G* and *H* and *J* and *K*, and the current turned on, thereby heating the portion of the thick piece which lies between the clamps. The abutment *U* and the thin piece can touch the work if desired. The current flows from one terminal *G* to the other terminal *H* and through the work. When the thick piece is sufficiently heated, it is moved back, together with its clamp, until it bears snugly against the abutment *U*, and at the same time the slide *O* is moved to bring the thin piece of work held in jaws *P* and *Q* up against the thick one. The current is then turned on to the welding transformer *B* and, if necessary, can be turned off from the heating transformer *A*. When the current is turned on to the welding transformer, it flows from the jaw *R* through the abutting pieces of work to the abutment *U*. As the pieces of work soften, suitable pressure is applied to the lever *V* to produce the necessary upset and effect the weld. The current is then turned off and the levers released to free the work.

Tee-welding Thin Strip Stock. — In the butt-welding of thin strip stock, the top of the tee has much more volume than the end of the lower portion of the tee that is to be welded to it, as is illustrated by the pieces *a* and *b* in Fig. 12. It is desirable to provide a means for localizing the current so that the piece *a* will heat up equally with the piece *b*. The method of accomplishing this is to first heat the piece *a* and then subject it to end pressure to upset it and form a burr or projection as shown.

This provides means for localizing the current at the point of welding in the subsequent stages of the operation. The piece *b* is then welded to the piece *a* by bringing the former into engagement with the upset and subjecting it to both heat and pressure. With this type of apparatus, it is evident that three sets of clamping jaws are necessary. The condition of the

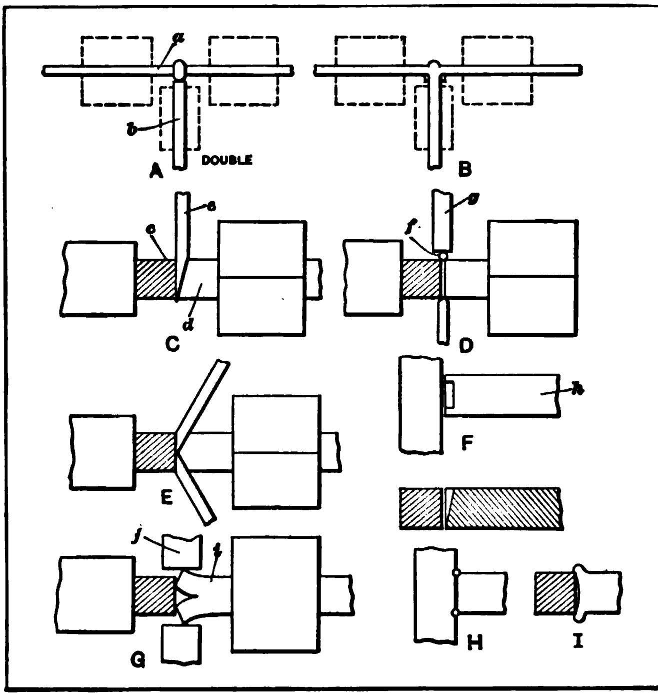


Fig. 12. Method of making a Tee-weld on Thin Stock, also Method of making Tee-welds without reducing Original Dimensions of Parts being welded

work before and after welding is shown at *A* and *B*. This process of electric welding was patented by the Thomson Electric Welding Co., in November, 1913.

Tee-welding without Changing Original Dimensions of Work. — A special application of the electric welding machine to tee- and angular-welding without changing the original dimensions of the work is diagrammatically shown in Fig. 12. This method

can be used advantageously in the construction of articles such as metal grills, grids or frames employing a number of cross pieces united to end pieces. In the usual practice of uniting pieces by a butt-welding process, there is, of necessity, a shortening of the piece attendant upon the upsetting of the plastic metal at the joint under endwise pressure. This involves a change in the dimensions of the completed structure. Hence, in the welding of a frame or grid having two or more cross pieces of definite dimensions, it is evident that, by the ordinary method of butt-welding, a certain amount of the metal is taken up in the upset and hence the pieces would be shortened. The methods illustrated in Fig. 12 consist in holding the pieces to be welded rigidly in their ultimate relative positions and crowding in a uniting material which is made plastic by the passage of an electric current through it. The metal is crowded into the space between the two pieces and fills up the joint, welding the members together.

One method of uniting two members in this manner is shown at *C* in Fig. 12. The pieces *c* and *d* to be joined are separated by a wedge *e* which is forced in sideways in the space between the two pieces. This metal may be of the same character as that of *c* or *d*, or different, according to the kind of joint required. By passing a current through these pieces, the metal wedge becomes plastic and adheres to the pieces, joining them without change of dimensions in the structure or shortening of either of the component parts. Any part that is left projecting from the wedge-shaped piece *e* is cut off after the welding of the joint is completed.

Another method of making the same joint, where only moderate strength is required, is shown at *D*. In this case, a small piece of metal *f* is being crowded into the intervening space between the two pieces by means of the crowding tool *g*. A slightly different application from that shown at *C* is shown at *E* where two pieces instead of one are used to form the junction. At *F* is shown another method. In this case, a bevel groove is cut in the piece *h*, providing it with a seat for the metal which is inserted to form the junction. Still another

method of effecting a tee-weld without any change in the original dimensions of the pieces is shown at *G*, in which the end piece *i* is flared out to provide material which is forced back by means of the crowding tool *j*. In this case, however, it is obvious that the plastic material is not a separate piece, but consists of one of the parts itself. The flare, instead of being as shown at *G*, can be as shown at *I* and will engage the other piece on the corners instead of in the center, so that the action

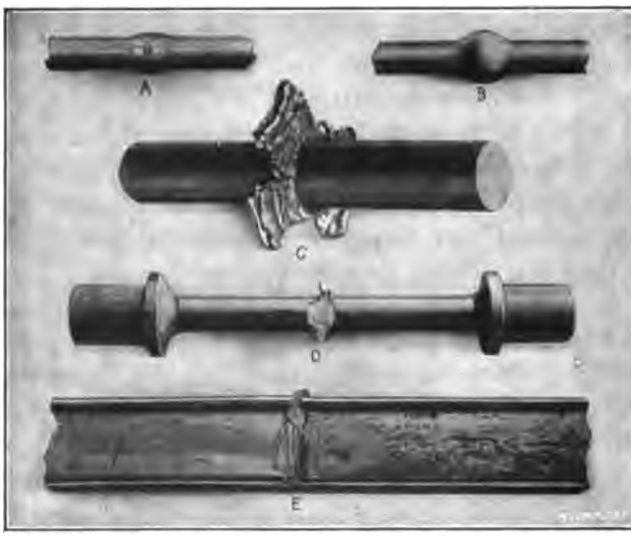


Fig. 13. Examples of Electrically Butt-welded Work showing Upset and Flash Welds

of the crowding tool will force the metal down into the center when making the junction. Another method of accomplishing the weld is shown at *H* in which the joining metal is applied in small pieces or spots at the corners, this method being especially adapted to the tee-welding of parts where a strong joint is not essential.

Work done on Butt-welding Machines. — Fig. 13 shows a group of work that has been welded on a butt-welding machine. The example shown at *A* is known as an upset weld; this does not take as much metal as a flash-weld, but requires a con-

siderably longer time to make. The method of making an upset weld is to reduce the amperage and take a longer time to heat the metal. This type of weld is used where it is not necessary to have the work highly finished and no flash need be removed. The example shown at *B* is known as an upset; the work is clamped between the jaws of the welding machine, the current turned on, and the jaws gradually brought together until the work has been upset to the required diameter. The work is then quickly removed and placed under a press or other machine and flattened out.

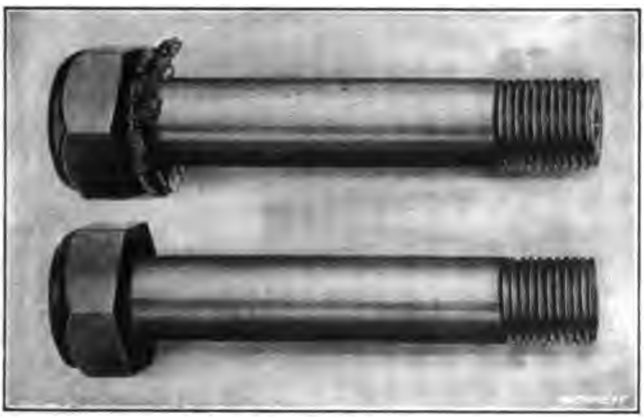


Fig. 14. Electrically Butt-welded Cap-screw

At *C* is shown a flash-weld. A considerably greater amount of material is used in making a flash-weld than an upset weld, but it is done much quicker. A flash-weld on some materials, such as brass, etc., is preferable because all the burnt metal is forced out into the flash, and a much better weld is secured. It is also possible to bring the two members that are welded into much better alignment with a flash-weld than with an upset weld. The examples shown at *D* and *E* are also flash-welds, the one shown at *D* being a round section, while the one at *E* is an I-beam section.

Welding Heads of Cap-screws. — Another common example of butt-welding is shown in Fig. 14. In the manufacture of

large cap-screws, it is found much more economical to make the cap-screw from two pieces and then weld them electrically than to turn down the body part from a large bar. In making cap-screws by the electric welding process, the first step is to make the stem, thread it, and finish it complete, and then to turn the hexagon head from another bar. In electric welding, the two members that are to be joined should preferably have the same cross-sectional area; therefore, it is necessary to turn down the front part of the head to the same diameter as the body of the cap-screw and to have it of a length equal to that

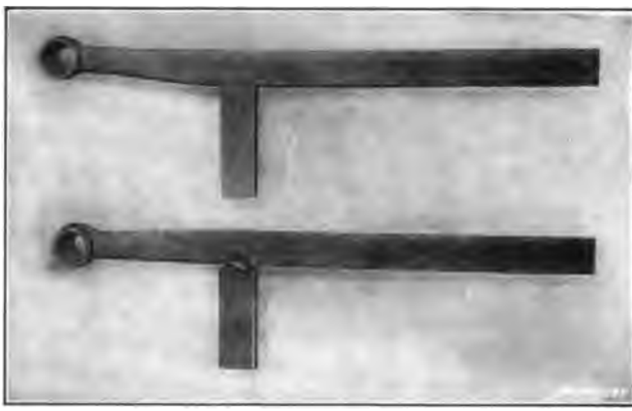


Fig. 15. Example of Tee-welding on Rectangular Work performed on Butt-welding Machine with Special Arrangement of Clamping Jaws

necessary to form the weld, generally about from one-quarter to one-half the diameter of the cap-screw. The head of the bolt is then held in one pair of jaws of the electric welding machine, and the bolt in the other, and both are brought together and welded, the jaws being made to conform to the shape of the two parts.

Tee-welding. — An example of tee-welding is shown in Fig. 15. This work can be done on a butt-welding machine by a special arrangement of the jaws. When it is desired to weld a piece of iron to the middle portion of another bar of equal size or larger, it is necessary to preheat the middle portion of

the bar to a bright red, then bring forward the other bar, the end of which is presented to the first one, and again turn on the current, when a weld can be made quickly. Special machines are built for handling this class of work, in which three pairs of clamping jaws are used instead of two.

Corner-welds. — Two different types of corner-welds are shown at *A* and *B* in Fig. 16; the corner-weld shown at *A* is

Fig. 16. Examples of Angular and Straight Corner Welds and Jump-welded Piping accomplished on Electric Butt-welding Machines

an angular weld, and can be performed in a butt-welder without any special arrangement of the clamping jaws, as shown at *G* in Fig. 9. The corner-weld shown at *B* is a square weld and has to be handled in a manner similar to that described for making a tee-weld, except that three jaws are not necessary, as is shown at *E* in Fig. 9.

Jump-welding. — Jump-welding is another type of welding that can be handled on a butt-welding machine. When welding

two rods in a jump-weld, one piece is held parallel with the opposing faces of the clamping jaws and the other at right angles to the first piece. The piece that is held as in butt-welding is sometimes pointed so that its cross-sectional area at the point of contact with the vertical piece will be reduced. Two examples of jump-welded tubing are shown at *C* and *D* in Fig. 16; *D* shows a jump-welded section which has been torn apart to illustrate how tenaciously the weld holds. Another example of butt-welded tubing is shown in Fig. 17. This piece of work comprises a hollow irregular-shaped tubing which is butt-welded at an angle. The manner of accomplishing this is shown in Fig. 9, at *G*.

Fig. 17. Corner Weld on Irregular-shaped Tubing

Examples of Butt-welding. — Fig. 18 shows a collection of examples of butt-welded work: *A* shows a hollow steel knife handle welded to the knife blade, showing a sharp fin at the joint. The blade and the German silver prongs of the fork shown at *F* are formed on the end next to the handle practically to the same shape as the smallest end of the handle; that is, the end of the fork or knife is hollowed out into the shape of a tube so that it presents the same cross-sectional area as the lower end of the handle. This is the best way to handle this work, but, in some cases, it is not necessary to do this. At *B* is shown a piece of high-carbon steel which has been butt-welded, and the nature of this weld is clearly indicated by the rugged fin; *C* shows a piece of softer steel with a smooth round swelling made by the weld, which took less current, but more time, to make. This weld is more in the nature of an upset weld. At *D* are shown two sizes of steel rods welded and upset into a smooth round button or shoulder; *E* shows two steel cups which have been welded together to form a caster,

the point of the weld here being indicated by very sharp fins; *G* shows two pieces of rectangular stock which have been cross-welded and "mashed" together; *H* shows two pieces of angle-iron which have been welded at the corner; *I* shows two different sizes of pipe tee-welded.

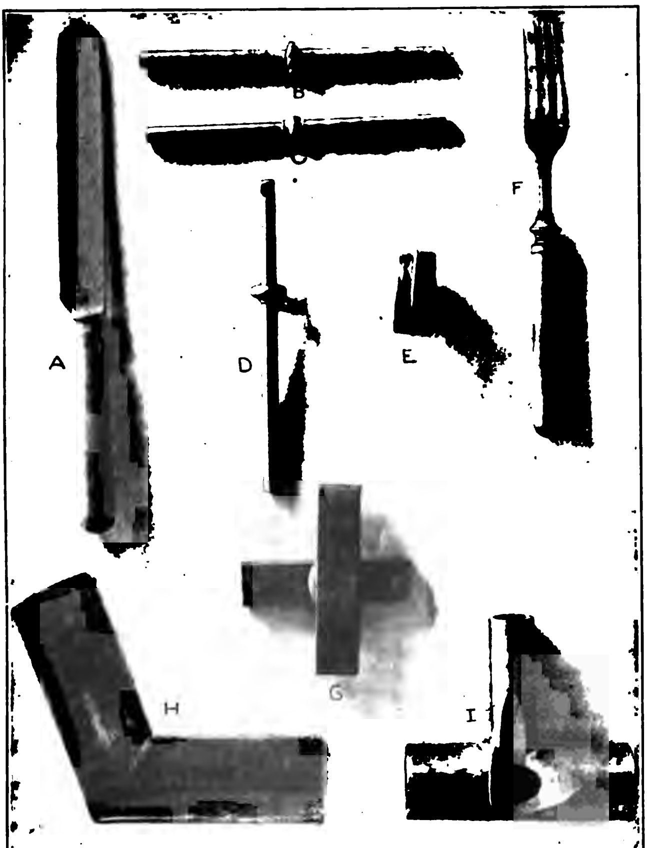


Fig. 18. Examples of Butt-welded Work

Another group of miscellaneous examples of butt-welded work is shown in Fig. 19, where *A* is a leaf of an automobile spring with a weld in the center; *B*, the nose of pliers welded; *C*, a rod upset on one end; *D*, ends welded on a cotton-mill steel flyer; *E*, a carriage step; *F*, a foot piece welded on a treadle

step; *G*, an iron frame; *H*, a vertical oblique weld in flat steel; *I*, a cross-weld in two rods; *J*, an iron magnet ring; *K*, a pipe welded to a flange; *L*, a rod welded to a disk to form a gear blank; *M*, one end welded to a crankshaft. The places where

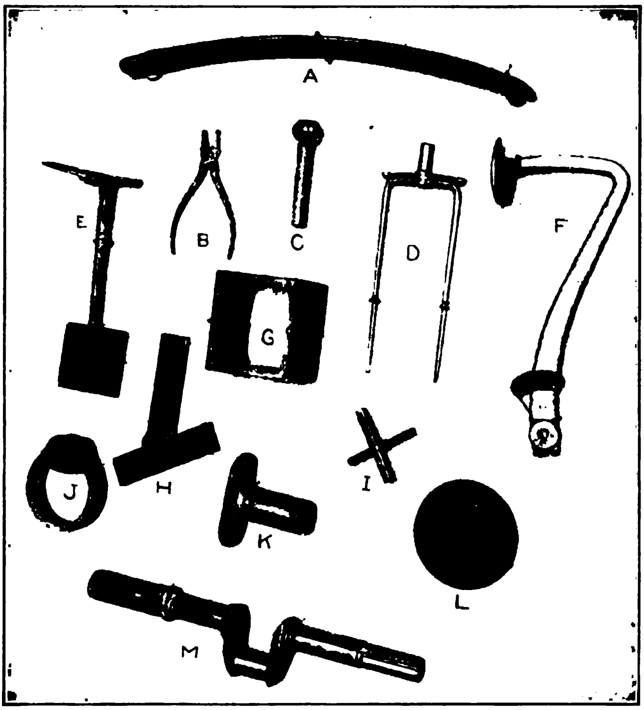


Fig. 19. Examples of Butt-welded Work adapted particularly to the Automobile Industry

the welds are made are seen by the swelling or burrs at the joints.

Fig. 20 shows a common and very valuable use of the electric butt-welding machine for joining high-carbon or high-speed steel to low-carbon steel. To the right of this illustration, at *A*, *B*, and *C*, are shown a diamond-point turning tool, side-facing tool, and round-nose turning tool, all made from high-speed steel, which have been welded to ordinary soft carbon-steel shanks. In this way, the cost of the tool has been reduced

but its life has not been shortened in any way. To the left of the illustration is shown a counterbore before and after repairing. The counterbore shown at D had one tooth broken. The shank was then cut off and welded to a new piece of tool steel, as shown at E, making the counterbore ready for recutting and hardening. At F is shown a center which has been broken, and at G the center repaired. At H is a shank end welded to a drill and at I is a long shank welded to a short drill. The

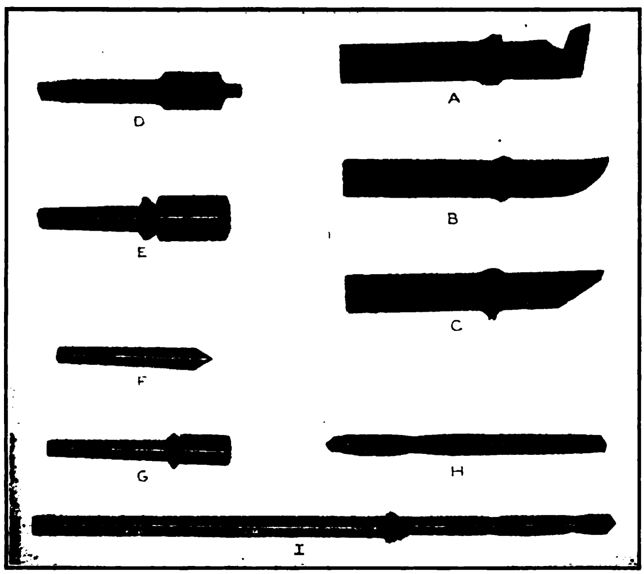


Fig. 20. Butt-welded Work adapted to Tool-room and General Machine Shop Requirements

examples shown are such as are commonly found in the machine shop, and illustrate the application of the electric welding machine to general repair and tool work. Nearly all extension drills made at the present time have their shanks welded to high-speed steel cutting parts, the shanks being made of ordinary cold-rolled steel. In fact, a large number of drills of standard lengths are made in this way.

Other Uses of Electric Welding Machines. — In addition to welding, a large number of other operations can be performed

on electric welding machines. One use is the annealing of hardened steel plates and other articles so that they can be drilled or machined. The terminals of the welding machine are connected to each side of the article to be annealed. Enough current is then applied to heat the metal sufficiently to soften it. This process is also applied to the manufacture of springs, where it is found necessary to take the temper out of the ends in order to flatten them. As a rule, however, special machines are designed for handling this class of work. Electric heating for hardening and tempering is also one of the uses for a welding machine. This is done by clamping the stock in the dies of a butt-welding machine, then turning on the current and bringing the metal to the proper temperature for hardening, whereupon it is quickly removed and quenched in the usual manner. As the metal is in plain sight of the operator, this is an ideal method of heating many classes of work.

Another operation that is commonly handled on electric welding machines is the riveting and heading of rivets, obviating the objectionable noise from pneumatic hammers and the heating of rivets in the forge fire. After the hole in the work has been punched and the rivet inserted, the electrodes of the welding machine are pressed against the ends of the rivet, which are quickly heated. The electrodes are then brought together to shape the form on the head. Electric brazing can also be handled rapidly on the welding machine. When the work permits of its admission into the jaws of a welding machine, brazing becomes a comparatively simple operation. After the work is clamped in the jaws, the current is turned on. When the metal has heated sufficiently, the spelter and flux are applied and allowed to run into the joints. Having the work under absolute control and in full view offers many advantages for electric brazing.

Power and Time Required for Electric Butt-welding. — For electric welding, single-phase or one phase of a multiphase system alternating current of from 100 to 500 volts, 40 to 60 cycles, is required. For other cycles, a special transformer must be used in the welder to adapt it to the higher or lower

frequency. For voltages higher than 440, the handling becomes somewhat dangerous, so that a special switch mounted on the wall at some distance from the machine must be furnished. This prevents any possibility of the operator coming in contact with the current when operating the machine. Direct current is not employed for resistance welding, because there is no simple way of reducing the voltage without interposing resistance, which uses up the power. For instance, a direct-current plating dynamo will give approximately 5 volts, which would be sufficient for certain kinds of welding, but lighter work calls for less current. By putting resistance in the line to take care of this decrease, the resistance uses up the power instead of allowing this power to do useful work. All electric welding machines are provided with transformers which reduce the voltage to from 3 to 5 volts.

The power and time required for electric welding varies with the cross-section of the stock and the material being welded. Copper and material offering a small amount of resistance to the passing of the electric current require a higher amperage to heat than other materials that offer more resistance to the flow of the current. Welds on copper, brass, and high-carbon steel must be accomplished very rapidly if good work is to be secured, and hence the amperage used is higher than for low-carbon steel or wrought iron. The regulator, however, can be shifted until the correct amount of current is supplied. It is always desirable to have ample power to make the weld in the quickest possible time, as better results are usually obtained, and both time and power saved. A $\frac{3}{4}$-inch round rod of wrought iron can be welded with 15 kilowatts in fifteen seconds or with 23 kilowatts in six seconds, using, in the first case, $15 \times 15 = 225$ kilowatt-seconds, and in the second case, $23 \times 6 = 138$ kilowatt-seconds. Endless pieces, like rings, take more power for the same cross-sectional area, as the diameter of the ring decreases; copper and brass take more power and less time than wrought iron or steel of like sections.

Table II shows the kilowatt and time required to make welds on round wrought-iron rods or other sections, and the cost in

Table I. Time and Power Required for Butt-welding Various Materials

Area of Bar, Square Inches	Equivalent Diameter Round Bar	Equivalent Side of Square Bar	Approximate K.W. Required	Time in Sec. to Make a Weld
WROUGHT IRON OR STEEL BARS OR RODS				
0.25	9/16	1/2	6.0	20
0.50	13/16	23/32	10.0	28
0.75	1	7/8	13.0	35
1.00	1 1/8	1	18.75	40
1.50	1 3/8	1 15/64	29.5	44
2.00	1 5/8	1 27/64	33.0	57
2.50	1 3/4	1 19/32	38.0	63
3.00	1 15/16	1 3/4	43.5	70
4.00	2 1/4	2	56.3	80
5.00	2 1/2	2 15/64	61.7	90
6.00	2 3/4	2 29/64	69.0	98
BRASS BARS OR RODS				
0.125	13/32	23/64	6.0	10
0.250	9/16	1/2	12.0	14
0.375	11/16	39/64	12.6	17
0.500	13/16	23/32	15.0	20
0.750	1	7/8	25.0	22
1.000	1 1/8	1	29.5	28
1.250	1 1/4	1 1/8	37.0	32
1.500	1 3/8	1 15/64	43.0	35
2.000	1 5/8	1 27/64	53.0	40
2.500	1 3/4	1 19/32	60.0	45
3.000	1 15/16	1 3/4	66.0	49
COPPER BARS OR RODS				
0.0625	9/32	1/4	5.0	5
0.125	13/32	23/64	8.5	7
0.1875	15/32	27/64	12.0	9
0.250	9/16	1/2	18.0	10
0.375	11/16	39/64	28.5	11
0.500	13/16	23/32	32.0	14
0.625	29/32	25/32	37.0	16
0.750	1	7/8	43.0	18
1.000	1 1/8	1	55.5	20
1.250	1 1/4	1 1/8	61.0	23
1.500	1 3/8	1 15/64	68.0	25

cents per kilowatt for 1000 welds. The price of current in different places varies, but the current here is figured at one cent per kilowatt-hour to give a basis for calculating the cost. Multiplying the price as given in the last column of this table by the current rate charged by local electric light companies will give the cost of current for 1000 welds.

Table I gives the kilowatt and time required for electric welding of wrought iron and steel, brass, and copper. This table does not correspond with Table II, as the time given for welding is quite different. The power required for electric welding varies inversely as the time consumed in making the weld. The operator can do this work quickly and use more current for a shorter period, or he can heat the stock slowly

Table II. Approximate Time and Current Required for Butt-welding Iron and Steel

Diameter of Rod, Inches	Area of Rod, Square Inches	Approximate K.W. Required	Time in Seconds to Make a Weld	Cost per 1000 Welds at 1 Cent per K.W.
1/4	0.05	2	3	$0.02
3/8	0.11	3.5	5	0.05
1/2	0.20	5	5	0.07
5/8	0.31	7.5	10	0.21
3/4	0.44	12	15	0.50
7/8	0.60	15	18	0.75
1	0.79	18	20	1.00
1 1/8	0.99	25	25	1.73
1 1/4	1.23	35	30	2.90
1 1/2	1.77	50	40	5.55
1 3/4	2.41	65	45	8.12
2	3.14	75	50	10.42

and use less current for a longer time. To do the work rapidly would require a larger generator and transformer capacity to furnish the desired current. The volumes of current used vary from 2000 to 50,000 amperes. The area of the bar has been converted into the equivalent diameter of round and the equivalent side of square bar, for convenience in use. It will be noted that the current required for the various materials differs considerably.

CHAPTER II

SPECIAL BUTT-WELDING MACHINES AND PROCESSES

As mentioned in the preceding chapter, many classes of work can be most satisfactorily handled in machines designed especially for that purpose. To meet this demand, a large number of special electric welding machines have been put on the market, and in the following some of the most important of these will be illustrated and described.

Electric Welding Machine for Taps, Twist Drills, etc. — In making extension drills, taps, etc., use is made of the electric welding machine, and for this purpose special types of machines are usually built. Fig. 1 shows a machine designed for this work. In this machine, work which has been finished can be electrically welded so that the two finished parts will come together in perfect alignment. The machine has sliding V-ways similar to those on a planer bed, which are scraped to a bearing and are provided with screw-adjusted long taper gibs, insuring accuracy in taking up wear of the moving parts. Stops with screw adjustments to back up and hold the work in perfect alignment are also provided. Each clamping lever is mounted on an eccentric that can be quickly adjusted for different sizes of stock. The current is turned on by touching the thumb-switch mounted on the compression handle, and the clamping jaws are accessible and can be quickly changed for varying sizes of work. The current regulator is mounted on the side of the machine and by means of this device the amount of current is under the complete control of the operator.

In welding extensions on taps or drills, the extension is made of low-carbon steel and the cutting part of the tool, from high-carbon tool steel. To make a satisfactory weld, it is, therefore, necessary to have the two materials protrude the proper distance from the faces of the clamping jaws. The amount that

the work should project from the clamping jaws is governed by several conditions, and, in this case, would be governed largely by the diameter and carbon content of the parts being welded. Low-carbon steel does not offer as much resistance to the flow of electric current as does high-carbon steel, and, consequently, should project farther from the clamping jaws. The low-carbon extension should project about 1.8 times its diameter from the face of the clamping jaws, and the high-carbon part,

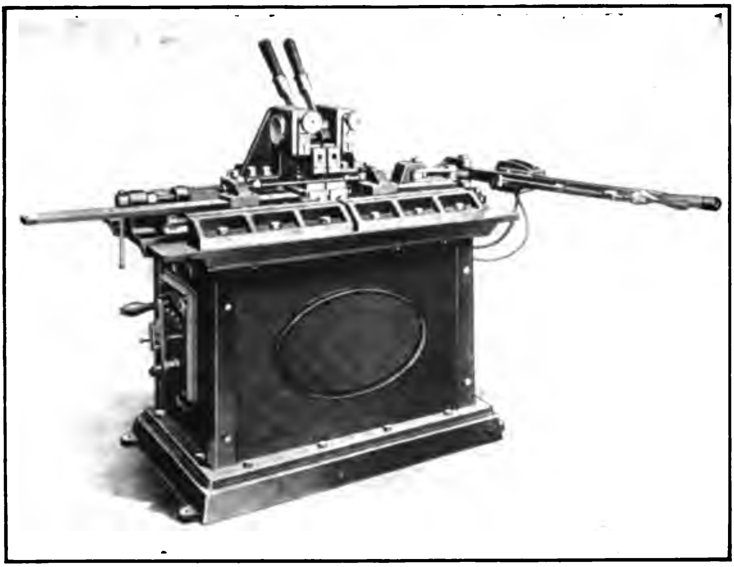


Fig. 1. Special Electric Butt-welding Machine designed particularly for Welding such Work as Extension Taps, Twist Drills, etc.

$\frac{5}{8}$ times its diameter from the clamping jaws. The welding of shanks onto taps and drills should be done very rapidly; that is, a large amount of current should be supplied, and the heating done quickly. A flash-weld is also preferable to an upset weld.

Hoop and Tire Welding Machines. — As a means of making steel automobile rims cheaply, welded strip stock has been adopted, and, for handling this work, special electric welding machines have been devised. Fig. 2 shows an electric welding

machine designed and built by the Thomson Electric Welding Co. for welding automobile rims. This machine will weld flat stock up to 7 inches wide by $\frac{5}{32}$ inch thick, and has a capacity of 30 kilowatts for 15 seconds. It is known as a "30-kilowatt electric welder" and is shown in the illustration with the clamps thrown open. In operating this machine, the hoop or rim is slipped in between the upper and lower clamping jaws with the ends of the rims abutting. The two upper clamping arms *A*

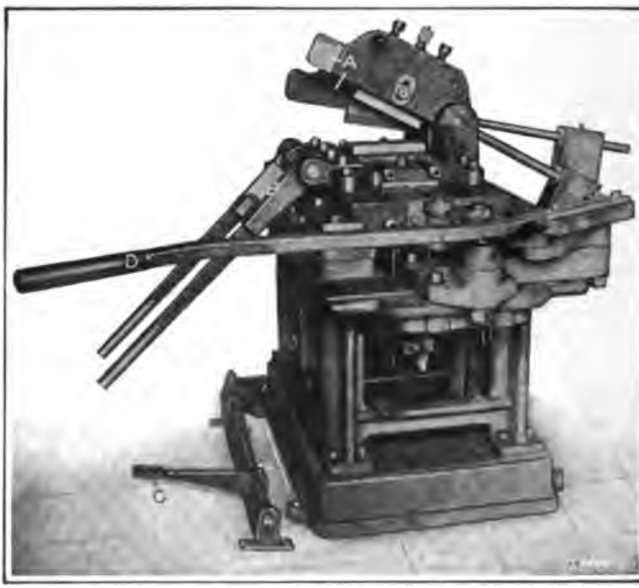


Fig. 2. Special Type of Electric Welding Machine built by the Thomson Electric Welding Co. for Welding Automobile Rims and Similar Work

are then brought down in contact with the work, and the handles or clamps *B* swung up so as to hold them in position. The current is then turned on by depressing the foot-treadle *C*, and handle *D* is operated. This moves the platen and brings together the abutting ends of the rim which are now highly heated, forming a weld. The machine is supplied with adjustable replaceable self-hardening steel jaws in the upper arms, which are also provided with balancing weights so that, as

soon as the clamping levers are removed, the upper jaws fly up. The platen is provided with ball bearings to facilitate its operation, and water is circulated through the secondary terminals and clamping jaws or electrodes to keep them cool.

Automatic Electric Tire Welding Machine. — Electric butt-welding machines for welding automobile rims, hoops, etc., are either hand-operated or of the semi-automatic type. A rim-welding machine of the semi-automatic type is shown in Fig. 3.

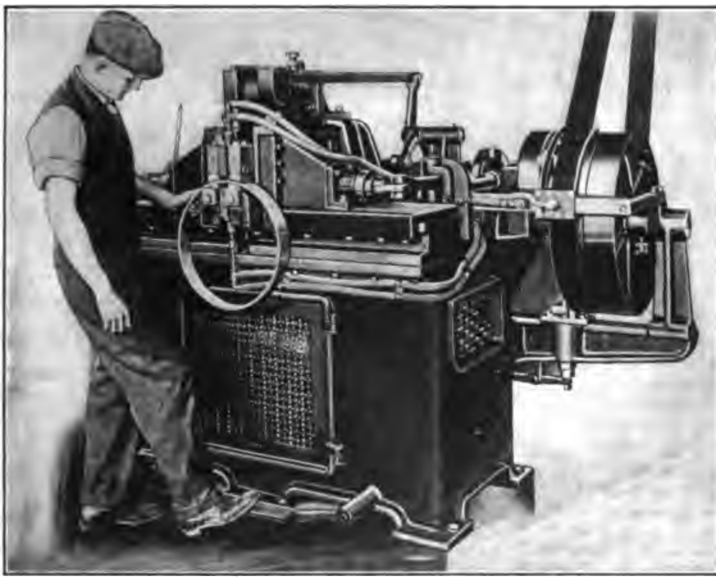


Fig. 3. Power-driven Automatic Butt-welding Machine especially designed for Welding Hoops, having a Maximum Capacity of 2- by 3/8-inch and a Minimum Capacity of 1- by 1/4-inch Flat Stock

The stock is rolled into hoop-shape and placed in the clamping jaws of the machine. The operator then depresses the foot-treadle shown at the front of the machine, whereupon the jaws instantly close and firmly grip the stock, bringing the ends of the hoop closely together. At the instant that the foot-treadle is operated, the current is automatically turned on and the stock begins to heat. In a few seconds, it reaches the welding temperature, whereupon the operator again depresses the foot-

treadle. This starts the machine, and the movable slide which is operated by a cam through connecting links and additional mechanism moves forward, bringing together the semi-molten ends of the metal, and as these come together, the current is shut off. For flattening the burr formed at the joint, a pair of steel forming dies is located between the clamping jaws and operated from the lower and upper surfaces of the work. After flattening the flash, the forming dies withdraw, the right-hand clamping die backs away, and the machine resets itself ready for the next cycle of operations. The operator then throws out the finished rim and places another in the machine, whereupon the cycle of operations is repeated. The entire working mechanism of the machine is controlled automatically with the exception of the foot-treadle. The parts of the machine that have to be varied for different classes of work are made adjustable, and when these have once been set in their correct position, the operation is comparatively simple. An example of work handled in the semi-automatic rim-welding machine shown in Fig. 3 is illustrated in Fig. 4. To the left of this illustration is shown a rim previous to welding, and to the right is shown a rim successfully welded. In this illustration, the joint has been flattened out so that the thickness of the rim at the weld is very little greater than anywhere else along the circumference of the rim.

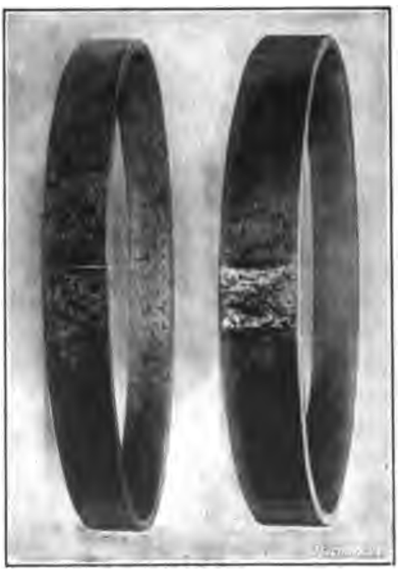


Fig. 4. Example of Hoop-welding performed on Butt-welding Machine shown in Fig. 3

Machine for Welding Tubes and Pipes. — Fig. 5 shows a pipe-welding machine which is capable of welding pipe up to

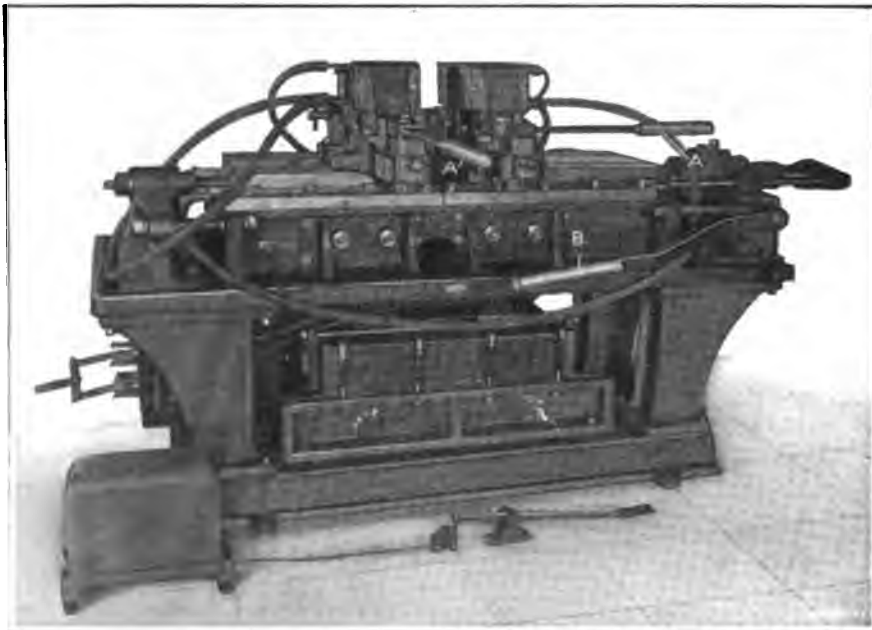


Fig. 5. Welding Machine adapted to the welding of Pipe and Tubing

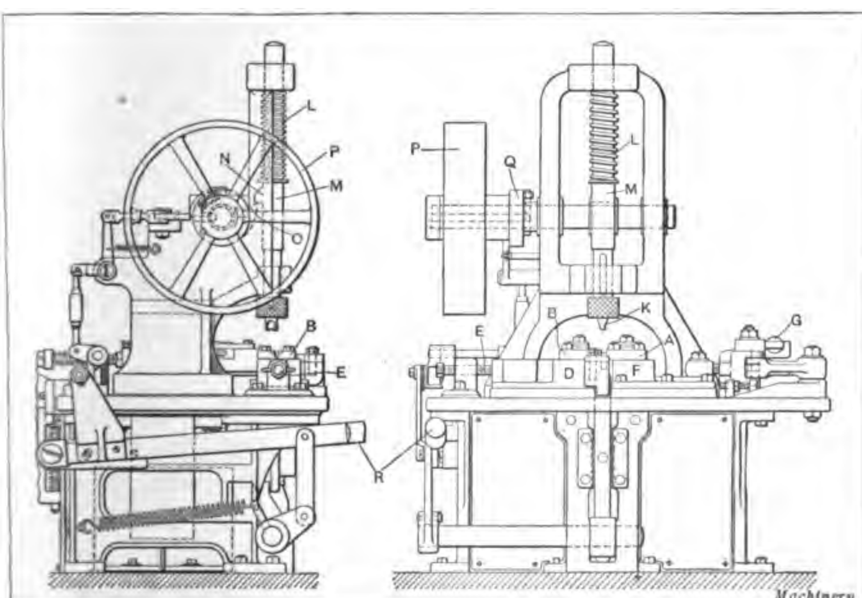


Fig. 6. Chain-welding Machine designed and built by the Thomson Electric Welding Co.

4 inches in diameter or boiler flues up to $5\frac{1}{2}$ inches in diameter, and has a capacity of 60 kilowatts for 50 seconds, producing 100 welds with 83 kilowatt-hours. This machine has water-cooled removable gun-metal clamps into which the pipe is dropped. The movable slide is operated by a twelve-ton double-acting oil jack mounted at the right-hand end of the machine, and the break-switch for throwing the current off and on is controlled by a foot-treadle. In operation, the tubing is either dropped into the clamping jaws or pushed through them until the two ends of the pipe meet midway between the jaws. Levers *A* are then drawn together, tightening the clamping jaws on the work. The foot-treadle is then depressed, turning on the current, and the ends of the pipe immediately begin to heat up. The jack-lever *B*, operating the oil jack, is then moved up and down two or three times to force the molten ends of the pipe together. The foot-treadle is now released, shutting off the current; the clamping levers are thrown back and the tubing removed, leaving the machine ready for the next weld.

Another type of pipe-welding machine is shown in Fig. 7. This machine has a capacity for welding extra heavy pipe up to 2 inches in diameter, or round bar stock $1\frac{1}{4}$ inch in diameter. The maximum power required is 35 kilowatts. The machine is provided with vertical clamping jaws, which particularly adapt it for handling tubing. The work to be welded is clamped between the copper jaws by levers *A*. These levers operate similarly to a quick-acting eccentric vise. The work is placed in the two clamping jaws with its ends abutting. The current is then turned on by operating a foot-switch, not shown, and the stock quickly reaches a welding temperature. Two or three strokes of the pump-handle *B* connected to the five-ton hydraulic ram then force the molten ends of the metal together to make a perfect weld. The clamping levers operate in a horizontal direction and do not interfere in any way with the pipe clamped in the jaws. These levers are long and are designed to clamp the stock so firmly that backing-up stops are not necessary when ordinary pipe is to be welded. The dis-

tance between the clamping dies can be regulated by means of adjusting screws located at the left-hand end of the machine. This allows the operator to set his machine for a certain amount of upset on the stock.

An example of welded work that can be handled on a tube-welding machine is shown in Fig. 8. This shows a piece of tubing welded to a stamping that is used for an automobile rear-axle housing. In welding tubing to forgings, or tubing to

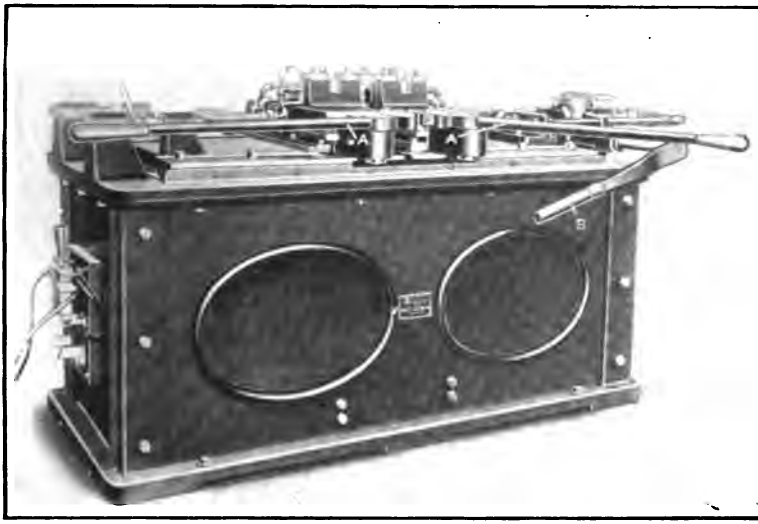


Fig. 7. Special Electric Butt-welding Machine designed especially for Welding Extra Heavy Pipe up to 2 Inches in Diameter

tubing, a flash-weld, as previously mentioned, is generally made, except in the welding of hydraulic piping, where particular care must be taken to produce a good weld without flash.

Preparing Tubing for Welding. — Tubing or piping that is to be welded should be cut square on the ends so as to abut evenly. To avoid having the upset decrease the inside diameter of the pipe, the abutting ends should first be flanged outward to a slight extent so that the ends, when under pressure, will force the upset to the outside. Instead of flanging the inside edges, one or both tubes can be chamfered slightly so that there

will be a recess into which the upset metal can pass. If tubing is rusty or scaly, it should be brightened at those spots where it is in contact with the clamping jaws and where it abuts. This can be done quickly on a grinding wheel. It is possible to weld tubing or ordinary pipe, and especially pipe with thick walls, by clamping the work in a V-shaped jaw, where but four points are in contact; or with one flat and one V-jaw, giving a three-point contact. By using the latter type of jaw, one set can be used for several different sizes of pipe.

Fig. 8. Tubing welded to a Stamping; Weldings of this Character can easily be handled on Butt-welding Machines especially designed for this Work

In the welding of hydraulic piping, special care must be taken to eliminate the flash on the inside of the pipe, as mentioned. This may be done as follows: The ends of the pipe are not chamfered, but an upset weld instead of a flash-weld is made. The pipe is clamped in the jaws of the welding machine, heated and compressed to make a slight upset. Then, while the metal is still hot, the outside diameter of the pipe is rolled down with a pair of special piping tongs to bring it to uniform size. By taking care, the inside of the pipe will show

very little, if any, upset, and, by inserting a mandrel inside the pipe at the time that it is being compressed with the tongs, it can be made perfectly smooth.

Electric Welding Machine for Chain Links. — Another application of the electric welding machine for manufacturing purposes is that employed in the welding of chain links. Fig. 6 shows a chain-link welding machine built by the Thomson Electric Welding Co. In this machine the work-holders are so constructed that they do not require manipulation prior to the operation of the machine. A mechanism is also provided for hammering the chain links after heating, in order to reduce the burr or upset produced in the electric butt-welding operation.

Referring to Fig. 6, the chain links which are to be welded are clamped longitudinally and in a horizontal plane between the left- and right-hand clamping dies *A* and *B* with the open side of the links facing the rear of the machine and in line with the contact electrodes *C*, Fig. 9. The work-holders are firmly bolted in a suitable recess in the die-slides, which can be adjusted to slide horizontally in a right- and left-hand direction from each other. The left-hand slide *D*, which is normally held stationary, is mounted between guides formed on the table and is adjusted longitudinally by stop-screw *E*. The right-hand horizontal die-slide *F* is actuated by a double toggle through a long hand lever *G*. The clamping dies *H* and *I*, Fig. 9, are provided with shallow link clamping recesses cut in their upper surfaces, and each of these recesses conforms substantially with the plane or outline of the links that are to be welded. The electrodes *C* can be moved sideways to bring them into contact with the work, so as to draw the open end of the link together. The electrodes are actuated by a foot-treadle (not shown) through an equalizing yoke; this foot-treadle projects from the front of the machine near the floor. The double-ended lower hammer die or anvil *J*, which acts in conjunction with hammer *K* to flatten the flash formed at the welded joint, is a flat oblong piece of hardened steel mounted with its working end beneath the clamping position of the chain link. This anvil is made with interchangeable

ends so that when one working end becomes worn or softened, by contact with the heated chain link, it can be reversed and a new end brought into position. The hammer *K* is mounted directly above the anvil. A tripping device lifts the hammer against spring *L* and then releases it, the spring giving the required compression. The upper hammer *K* is held in the lower end of a vertically reciprocating die-shaft *M* provided with a projection *N* that engages one or more actuating cams or dogs

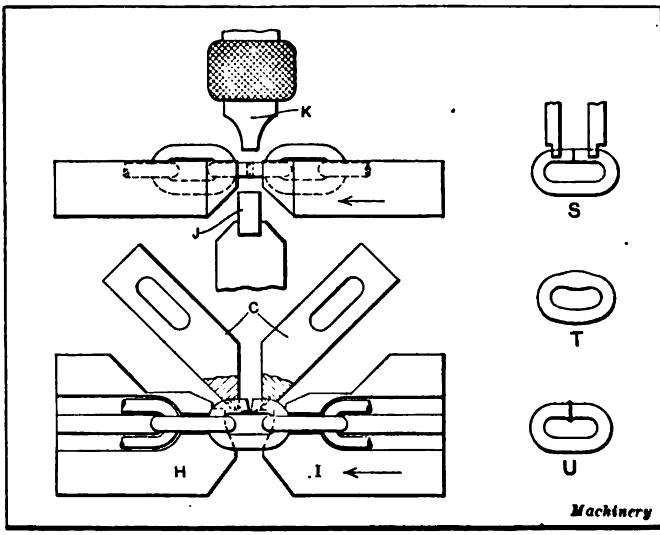


Fig. 9. Diagram showing Operation of Chain-welding Clamping Dies and Electrodes; also Results of Finished Work — Thomson Electric Welding Co.

O mounted on the camshaft; these dogs lift shaft *M* against the tension of spring *L*. Power is obtained from a flywheel *P* driven by a belt in the usual manner, which runs free until the clutch *Q* is engaged. The burr-reducing or link-finishing mechanism for both the anvil and hammer is controlled by hand-operated lever *R* extending across the left-hand side of the machine.

In operation, the link is centered and clamped between the holding dies with its abutting ends just out of contact. These

ends are then brought into contact by slightly increasing the pressure on clamping lever *G*. The contact electrodes *C* are then brought forward by pressure on the foot-treadle until they make contact with the side of the link which is to be welded. The primary circuit is then closed, thus producing a current in the secondary circuit or loop carrying the current to the electrodes. Meanwhile, the operator maintains an end pressure on the holding dies by means of the clamping lever. Since the contact of the open ends of the link is the greatest resistance in the circuit, the link rapidly heats up at this point and soon becomes plastic, spreading under the longitudinal pressure to which the abutting surfaces are subjected. As the ends of the link gradually upset, the operator quickly brings the holding dies closer together, thus completing the welding of the link. As clamping lever *G* reaches the position corresponding to the completion of the weld, the automatic current-controlling switch causes the circuit-breaker to operate and shuts off the flow of the electric current. The manner in which the electrodes force the open ends of the link together is clearly illustrated in Fig. 9.

After the weld has been completed, the end pressure of the holding dies is maintained by the operator and the foot pressure on the treadle is released, permitting the contact electrodes to back away from the work. Lever *R*, for operating the burr-removing mechanism, is then pressed downward, raising the anvil *J* into engagement with the upset portion of the link, and at the same time operating the upper hammer *K* that strikes one or more blows upon the still heated blank. Meanwhile the pressure on the holding dies is gradually released to permit the chain link to lengthen. After welding and drawing the links, lever *R* is returned to the upper position, thus depressing the anvil and raising the hammer, when the link is removed and the same operation repeated until the entire length of chain has been welded.

At *S* in Fig. 9 is shown another method of welding chain links. In this case, the welded portion of the chain link is reinforced by forcing a large amount of metal into the weld

and surrounding parts. This is an upset weld as shown at *T* rather than a flash-weld as shown at *U*. The cross-sectional area of the link is increased at the welded joint, making the link as strong at the joint as anywhere else along its section.

Manufacture of Electrically Welded Chain. — The chain manufacturer who produces a high-grade product must use material of uniform quality, and the finished chain must be tested to discover any weakness due to improperly welded links, burnt links, or other defects in material or workmanship.

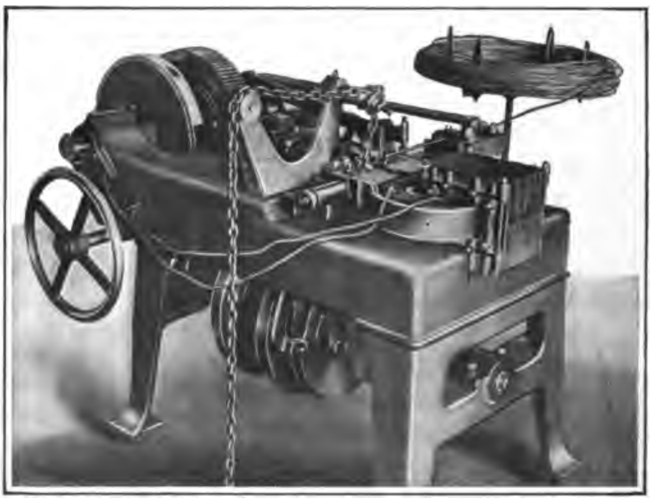


Fig. 10. Machine used for Manufacture of Electrically Welded Plain-link Chain, showing Welding Apparatus

In making such tests, a load equal to about one-half the ultimate strength of the chain is applied; and as the specified safe working strength of the chain is about one-half the load applied in making the test, the factor of safety allowed is approximately 4. In some cases, the specified strength of the chain is made one-third the ultimate strength, making the factor of safety only 3.

Welding Plain-link Chain. — Aside from the provision of the welding apparatus and the necessary mechanism to form the links of the chain, probably the most important requirement

of chain-making machines is that they be built very rigidly in order to stand up under the strains incident to the constant hammering and twisting which takes place while they are in operation. It is also important that the heat supplied by the welding apparatus be localized, so that it will not affect the different members of the machine. Figs. 10 and 11 illustrate a type of machine used for making plain-link welded chain, which differs in general appearance from the machine shown

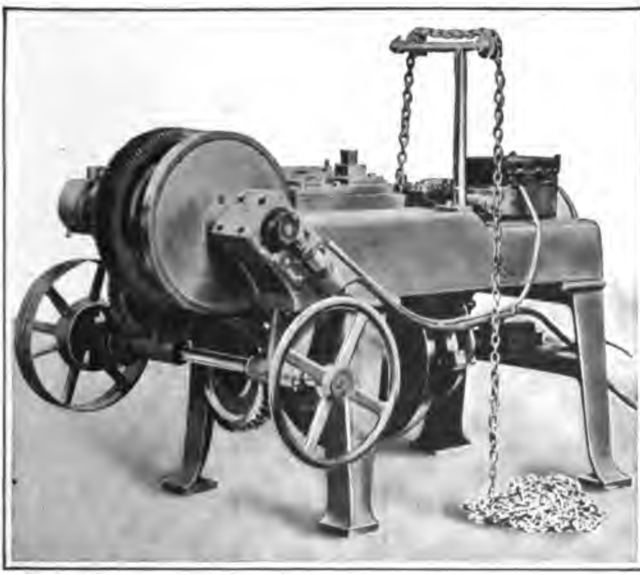


Fig. 11. Arrangement of Camshaft for Driving Cams which actuate Mechanism of Plain-link Chain-making Machine

in Fig. 6. The illustrations show the rigid form of construction that is adopted, both as regards the weight of the machine members and the compact way in which they are mounted on the bed. In operation, this type of machine receives the wire from a coil carried by a reel as shown in Fig. 10, straightens it, cuts off a blank of the required length for the size of link that is being made, forms the link and makes a scarf weld, each link being connected with the one previously made, so that a continuous chain is obtained. When working on $\frac{1}{4}$-inch wire, the

rate of production on this machine is from ten to twelve links per minute.

The steps involved in the manufacture of chain on this ma-

Fig. 12. Link Forming and Welding Mechanisms

Fig. 13. Mechanism at End of Forming Operation

chine are illustrated in Figs. 12, 13, and 14, which show plan views of the forming and welding mechanisms while in operation. Referring to Fig. 12, the wire *A* is fed up to a stop, which regulates

the length of the blank, while the forming plunger *B* is returning from the preceding operation. The arbor about which the links are formed is in the position indicated by *C*, but this arbor is hidden by the chain. As the wire is fed forward, the arbor rises to its upper position, and when it reaches the top of its travel, the wire is cut off by a knife carried on the outside of one of the forming slides, the position of the cut-off blade being indicated at *D*. After the blank has been cut off, it is held between the forming slides and the arbor, and the forming slides *E* and *F* con-

Fig. 14. Position of Mechanism shown in Fig. 13 after Welding Operation

tinue their forward movement and bend the ends of the blank around the base of the arbor. The arbor then drops to its central position and the forming plunger *B* moves forward and completes bending the blank around the smaller part of the arbor. As the scarfed ends of the blank come together, they pass through the link of the chain which was formed by the previous operation, and are laid over each other ready to be welded. At this stage of the operation, the position of the different members of the machine is shown in Fig. 13. The link is still retained in the forming plunger *B* which now makes one-fourth of a revolution to bring the link into position for welding, and at the same

time is advanced to the welding jaws *G* and *H*, where the link is electrically welded. Before the plunger moves forward to the welding jaws, the arbor *C* must drop to its lowest position, in order to free the link.

In the manufacture of electrically welded chain, the speed of production is limited by the time required for welding the

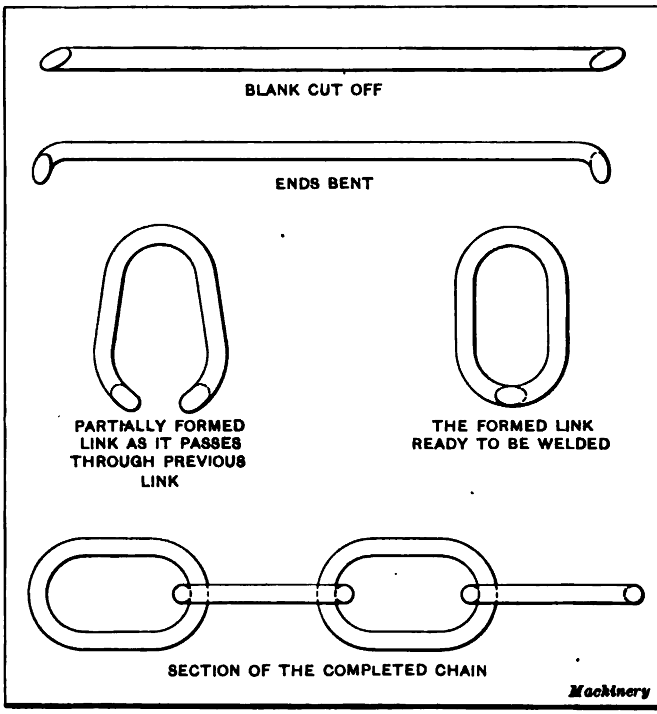


Fig. 15. Condition of Work after Each Step in Cycle of Operations

links, as the various forming operations require very little time. After each link is welded, it is drawn back to the trimming jaws *J* and *K*. In making the weld, there is generally a surplus amount of metal left at the joint, and while the link is still hot it is drawn back to the trimming jaws which consist of a pair of dies shaped to press the joint into the required form. While this final operation is being performed, the blank for the

next link is fed into the machine and the forming plunger *B* is moving back. During this backward motion, the plunger turns through one-quarter of a revolution in order to return to its original position. It will be remembered that the plunger *B* made a quarter turn during the operation of producing the link, which was for the purpose of having the finished link still held by the trimming jaws *J* and *K* in position to have the next link passed through it. In order to avoid twisting the chain into kinks, the plunger *B* is arranged to turn alternately through a

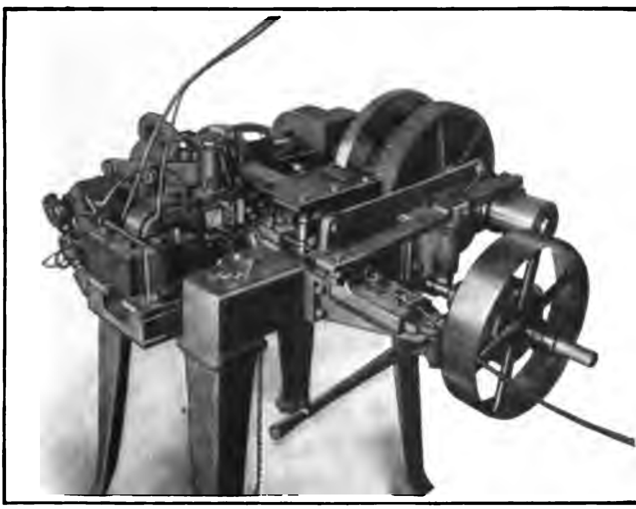


Fig. 16. Form of Wire-straightener used on Machine shown in Fig. 17

quarter of a revolution in the right- and left-hand directions. The operations of the various members of the machine are controlled by cams carried on a camshaft beneath the bed, this shaft being shown in Figs. 10 and 11. The camshaft runs at one-half the speed of the main driving shaft, the drive being through a train of spur gears and a worm and worm-wheel.

The preceding description of the method of producing chain on this type of machine may be briefly summarized as follows: 1. The wire is fed through to the stop. 2. The blank is cut off and has its ends bent by the side forming jaws *E* and *F*.

3. The forming of the link is completed by the forward movement of the plunger *B*, which closes in the ends of the blank

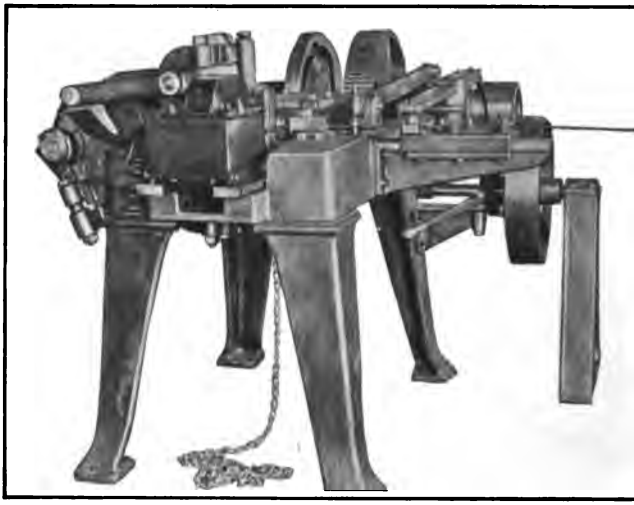


Fig. 17. Machine for Manufacture of Electrically Welded Twisted-link Chain

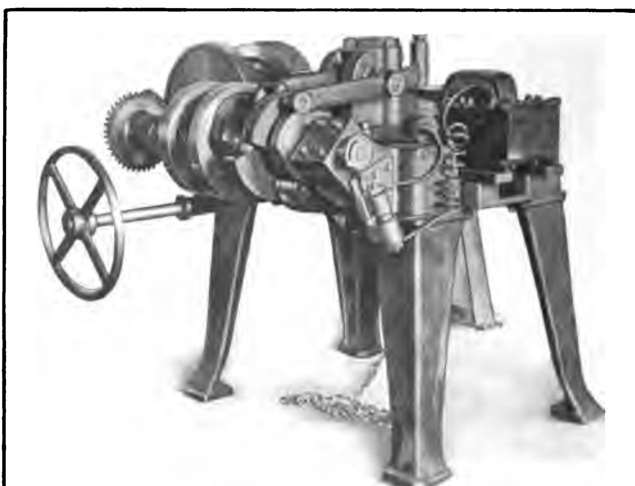


Fig. 18. Arrangement of Camshaft of Machine shown in Fig. 17

through the preceding link. 4. The plunger *B* turns the link through one-fourth of a revolution and carries it forward to the

welding jaws. 5. The link is returned to the trimming jaws which grip it and squeeze the excess metal from the weld. The condition of the work after each successive operation is shown in Fig. 15. This sequence of operations is repeated indefinitely until the required length of chain has been produced.

Manufacture of Twisted-link Chain. — Electric welding machines for the manufacture of twisted-link chain are shown in Figs. 16, 17, and 18. As in the case of the machine used for the manufacture of plain-link chain, the wire is taken from a coil

Fig. 19. Starting Point in making a Twisted Link

carried by a suitable reel and enters the machine through a straightener which removes all kinks in the wire. The design of the straightener on this machine is somewhat unusual, in that it slides backward over the wire while the wire is held by a clamp on the machine. In most wire straighteners, the wire is pulled through the straightener. The clearest view of the wire straightener is shown in Figs. 16 and 17.

In describing the operation of this machine, reference is made to Figs. 19 to 23, inclusive. The wire is first fed forward and cut off preparatory to having the ends of the blank bent by the auxiliary forming slides *A* and *B* which act in conjunction with

the two pins C and D on the extreme ends of the arbor support, Fig. 19. After this has been done, the arbor E moves to its

Fig. 20. Completing Bending of Link

Fig. 21. Welding Joint of Link

second position in front of the forming plunger F, which then moves forward to complete forming the link as shown at G in Fig. 20. In the course of this forming operation, the scarfed

ends of the wire are lapped over each other, the ends of the link being closed in through the link which was produced during the preceding cycle of operations. The link is now ready to be welded, and, in order to convey it to the welding dies, the arbor *E* drops down to allow the plunger *F* to carry the link forward to the welding dies *H*. In order to provide the necessary clearance, the trimming dies *I* have also opened. As the plunger *F* moves forward, it turns through a quarter of a revolution to bring the link into the welding position; and after the link has

Fig. 22. Trimming and twisting Link

been welded, the plunger *F* moves back conveying the link to the trimming dies *I* where the weld is shaped to the required form. These trimming dies grip the link as shown in Fig. 22, and the plunger *F* still retains its grip on the end of the link while it rotates through one-fourth of a revolution, thus producing the required twist in the link, which is the final operation of the cycle. The plunger *F* now releases its hold and moves back, as shown in Fig. 23, until it reaches its position ready for the beginning of the succeeding cycle of operations, this position of plunger *F* being shown in Fig. 19. The finished link is still held in the trimming dies ready to have the next link passed through

it. The operation of the forming plunger on this machine is controlled by a cam on the main driving shaft, and the rotation of the plunger is effected by a segment gear which meshes with teeth cut in the plunger; these teeth may be seen in Fig. 21.

The preceding description of the cycle of operations involved in the manufacture of twisted chain on the machine shown in Figs. 16, 17, and 18 may be briefly summarized as follows: 1. Feed the wire through to the stop. 2. Cut off the blank. 3. Bend the ends of the blank. 4. Complete forming the link

Fig. 23. Return of Bending Plunger

around the arbor, interlocking the link with the adjacent finished link in so doing. 5. Weld the joint. 6. Trim the joint. 7. Twist the link and return the mechanism into position for starting the next cycle of operations. The condition of the work after each successive operation of this cycle is shown in Fig. 24. The two types of chain which have been described constitute the bulk of the chain produced on automatic machines equipped with electric welding apparatus. These are the two types of chain which are used for a great majority of the purposes for which chain is employed. The links are of uniform shape, size, and strength.

Machine for Welding Rings. — A large number of rings are used in connection with chains, and Fig. 25 shows a machine employed for forming and welding rings for this purpose. As regards the principle on which it operates, this machine is essentially the same as the chain-making machine employed in the

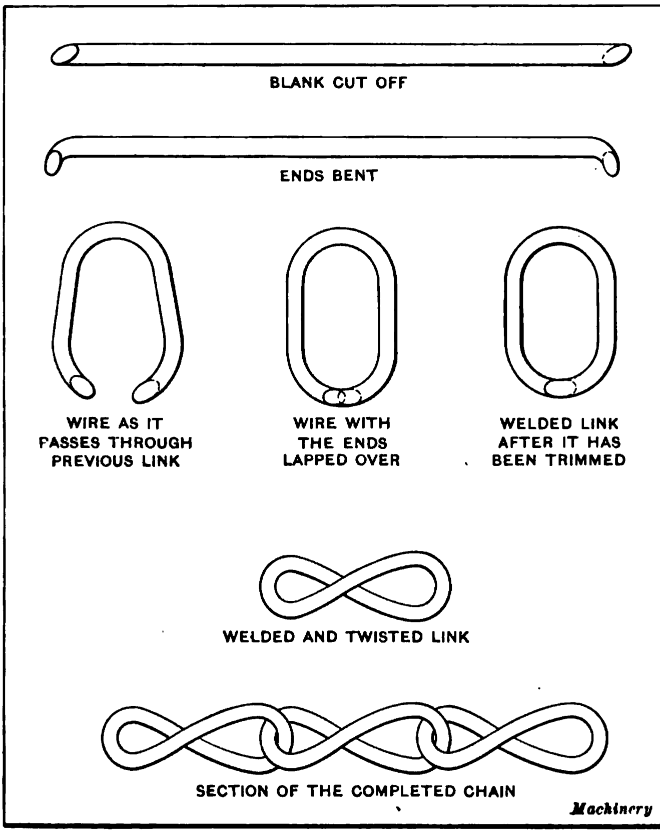


Fig. 24. Condition of Work after Each Step in Cycle of Operations

manufacture of plain chain, except that different tools are employed. The operations employed in the manufacture of rings on this machine are as follows: The wire is fed forward to a stop; the blank is cut off; and the ends of this blank are bent by auxiliary bending slides. Then the arbor drops down to a lower

position, allowing the plunger to come forward and complete the bending operation, which brings the scarfed ends of the blank together. The arbor now drops down out of the way and the plunger advances to the welding jaws, at the same time making a quarter turn to bring the ring into the proper position for welding. After the welding operations have been completed, the plunger moves back to the trimming jaws which form the welded joint. While the ring is held in the trimming jaws, the

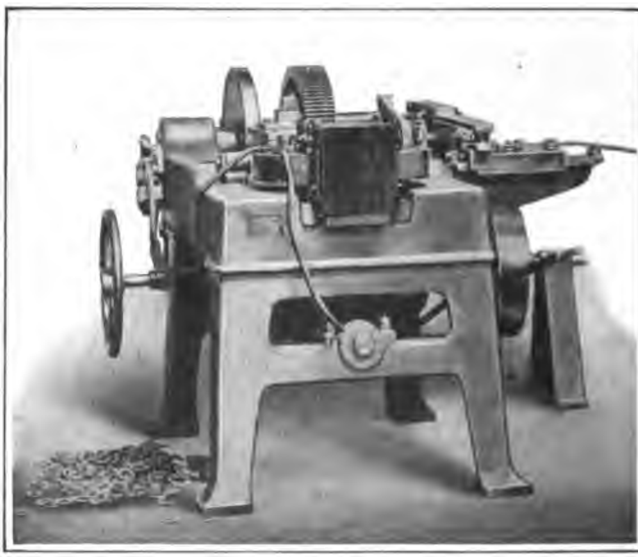


Fig. 25. Machine for Use in Manufacture of Electrically Welded Rings

plunger moves back to its starting position, and, while so doing, it must turn back through a quarter of a revolution. At the same time, the arbor moves to its highest position ready to have the next ring formed around it. This machine will make approximately twelve rings per minute when working on $\frac{3}{8}$-inch wire. The perfection of the welds produced is a most important matter in the manufacture of chain. In ordinary welding operations, the metal is sometimes heated beyond the proper welding temperature in order to provide for the loss of heat which takes place during the time which must elapse between transferring

the work from the forge to the anvil. This affords an opportunity for an oxide scale to form on the metal, which may result in a poor weld; but, in electric welding, the heating and welding of the work take place simultaneously, so that the chance of oxidation is practically eliminated, with the result that the likelihood of producing defective welds is greatly reduced.

Welding High-speed Steel to Tool Steel Shanks. — Owing to the high price of high-speed steel, many manufacturers have adopted the method of either using high-speed steel bits in tool-holders or welding them to tool steel shanks. Manufacturers of electric welding machines have been called upon to supply machines for this purpose, and have also been doing this work in their own shops to some extent. The work handed to them in many cases shows a lack of knowledge of the requirements which must be met if a satisfactory weld is to be made. It is essential, in resistance welding, to have the work clean and free from scale; and in making a butt-weld, the cross-sectional area of the two pieces must be nearly equal. An example which illustrates this point is shown at *A* in Fig. 26. One manufacturer sent a large batch of machine steel shanks to have high-speed steel tips welded to them, and thinking that it was necessary to have the tool rough-formed to shape, he beveled it on the front end as shown, and provided a seat for the block. To weld a tool of this shape is practically impossible, because the smallest section is that lying next to the electrode *a*. It is almost impossible to obtain a welding heat between the two pieces, as the greatest point of resistance is between the electrode *a* and the smallest section of the piece. The correct way to prepare the blank is shown at *B*, where it will be seen that the cross-sectional area of the block and shank are equal.

Another condition which makes welding difficult is shown at *C*. Here the manufacturer intended to increase the strength of the weld by leaving a rib *b* to back up the tool and resist the cutting action. With a holder or shank formed in this manner, it is a difficult matter to get the block and holder to weld at the points *c* as indicated. It also takes longer to make the weld, because of the danger of burning the parts, due to unequal

heating, caused by the difference in the cross-sectional area of the two pieces.

The easiest and quickest way to make a satisfactory spot-weld is shown at *D*. Here the lower surface of the high-speed steel block is provided with a series of points or projections. These

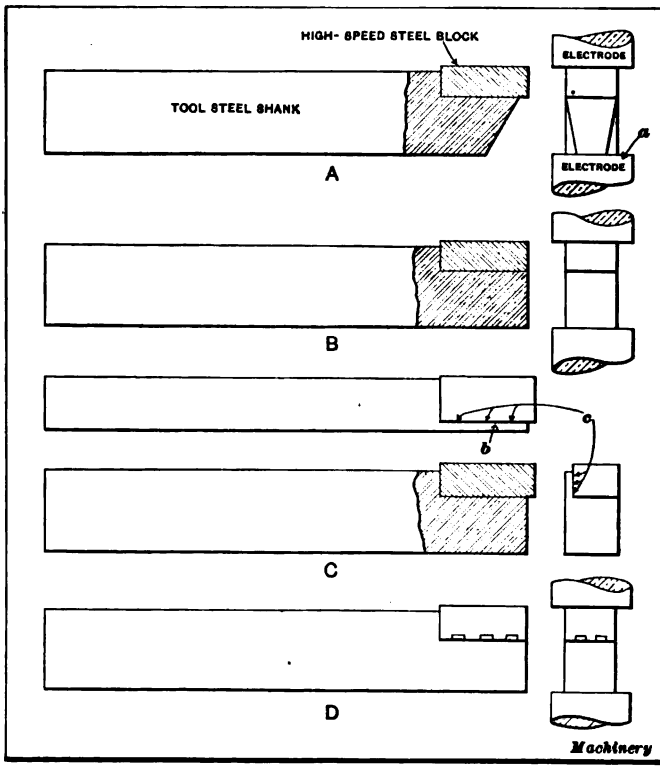


Fig. 26. Correct and Incorrect Methods of welding High-speed Steel Blocks to Tool-steel Shanks

points localize the current and permit an equal temperature to be obtained. The current and time consumed in making the weld is also much less than when the block and holder are provided with plain surfaces.

Another point that has troubled many manufacturers contemplating the use of electric welding machines for this work

is the type of welding machine that is the most suitable — a butt-welding or a spot-welding machine. As far as the welding of high-speed steel bits is concerned, either a spot- or butt-welder can be used. The butt-welder, however, has the advantage over the spot-welder that it is constructed so that a greater pressure between the electrodes can be obtained. Furthermore, it is more accessible. The machine to purchase for the work, however, depends, to a great extent, upon the product of the manufacturer. For instance, a manufacturer whose product consists chiefly of light work and sheet metal parts should purchase a spot-welder, whereas the manufacturer of fairly heavy machinery should purchase a butt-welding machine, because he can generally find other work for the welding machine to do, such as welding bolts, tie-rods, etc. The type of machine also depends upon the size of the tools to be welded. For welding large lathe tools, a butt-welder should be used, while for welding small bits, $\frac{3}{8}$-inch square, etc., a spot-welder could be employed to advantage.

One of the difficulties encountered in welding high-speed steel tips to tools is that of finding the correct relation between pressure, current, and time. The current and time are more easily ascertained than the pressure required, and it takes considerable experience to determine when the two materials should be brought together.

The welding of high-speed steel or high-carbon steel to the same kind of stock or to low-carbon steel can be accomplished by the electric welding process as easily as the welding of any other kind of metal. The only difference is in the handling of the material after the weld is made. When butt-welding two pieces of iron or low-carbon steel of the same kind, a perfect and homogeneous weld can be made without any subsequent operations; but when welding high-speed or high-carbon steel, it is necessary to overcome the stresses set up at the junction of the two pieces of metal by holding the heat in the pieces until they are of a uniform temperature. This heat-treatment relieves the tension caused by the unequal expansion and contraction of the metals. It is necessary to apply the same treatment

when welding dissimilar metals, like high-speed steel to low-carbon steel. When this is done properly, the two pieces are united so that a lathe tool made in this manner can be forged, annealed and rehardened, the same as if it were a solid piece of high-speed steel.

Fig. 27. Butt-welding Machine used for Welding High-speed Steel or High-carbon Steel to a Shank of Low-carbon Stock. The Current Cost, at Three Cents per Kilowatt-hour, should not exceed $1.50 for 1000 Pieces of 3/4-inch Square Steel which can be welded in a Day

Details of Tool-welding Process. — Fig. 27 shows the operation of an electric butt-welding machine used for welding high-speed steel bits to shanks. The stock is clamped in the vise-like jaws, the current is turned on, and the pieces instantly begin to heat. In a few seconds, they have attained the welding tem-

perature, and a pull on the lever handle forces the abutting pieces together. When welding two pieces of stock of the same kind, the pieces extend an equal distance from the clamping jaws, but when welding high-speed or high-carbon stock to low-carbon stock, the high-speed or high-carbon stock, being finer grained and offering more resistance to the flow of current, will heat more rapidly than the low-carbon stock. To overcome this, the stock should be placed in the jaws of the machine with the low-carbon stock extending out farther from the dies than the high-speed steel stock, as shown in Fig. 28. The difference depends somewhat upon the diameter of the stock to be welded,

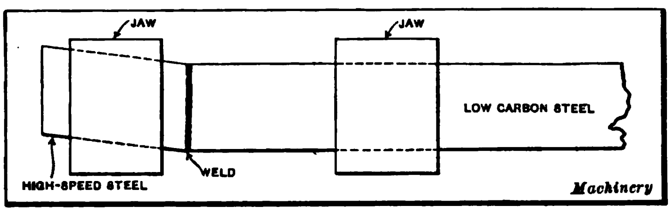


Fig. 28. Showing the Proper Relation of High-speed Steel and Low-carbon Steel Stock in the Welder Jaws

but it should be approximately one-third high-speed to two-thirds low-grade stock. The proportions can be quickly determined, however, by watching the heating. When both pieces heat equally, they are placed just right. The amount of metal taken up in the weld will be approximately one-half the diameter of the stock. For example, in welding a one-inch bar of stock, one-half inch will be taken up in forcing the parts together — one-quarter inch on each side.

Butt-welding is the ideal method of utilizing high-speed steel, as stub ends can be welded to a cheap grade of carbon steel and used up. When the high-speed steel is all used, the same shank may have another piece of high-speed steel welded to it. It is not necessary to saw or forge the high-speed steel to shape, as is required when preparing the stock for the spot-welding method as shown in Fig. 29. No welding compound is used, heat and pressure only being required.

Heat-treatment after Welding. — After the weld is made, the stock must be immediately placed in a furnace for heat-treatment. Stresses are set up that will cause the high-speed steel to check or crack if it is allowed to drop in temperature to any appreciable extent after the weld is made. In welding, the parts are heated

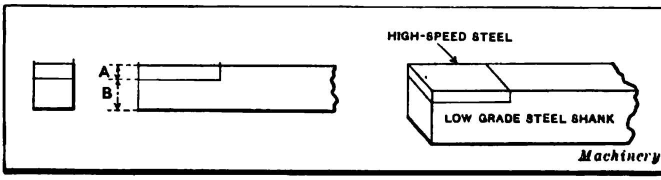


Fig. 29. Fitting High-speed Steel Pieces to Low-carbon Steel Shanks

only at the junction of the two pieces as shown in Fig. 28, and when taken from the machine, the heat radiates rapidly and unequally in the high-speed and carbon stock. This condition can be entirely overcome by proper heat-treatment. The welded pieces should be allowed to remain in the furnace for several hours and should be cooled very slowly in order to anneal them thoroughly. After annealing, they may be reheated, forged,

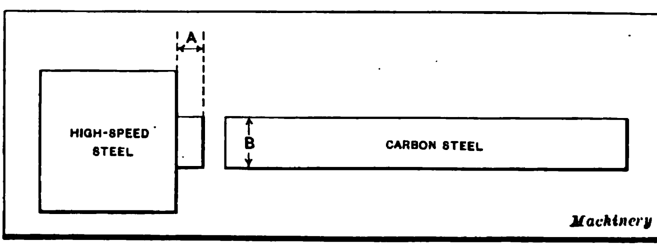


Fig. 30. Showing Reduction necessary on Large Piece before it can be welded to a Small Diameter Shank

and hardened, the same as solid stock. This process is used by drill manufacturers and makers of tools of different kinds that require high-speed or high-carbon steel to be welded to low-carbon steel shanks.

Welding Parts of Unequal Diameter. — Tools of various kinds may be welded, but the work in nearly all cases should be done

in the rough blanks. When welding a large diameter to a small diameter, the larger diameter must be reduced to the diameter of the piece it is to be welded to, as shown at *A* in Fig. 30. The length of the reduced section should be one-half the diameter of *B*. In making the upset, allow one-quarter of diameter *B* and the same amount at *A*. For example, if *B* is one inch, one-half inch should be allowed for the upset. A taper reamer can be welded when broken in the shank, but a twist drill cannot be welded if broken at the ends of the flutes, owing to the difference in cross-section of the metal in the two parts.

Spot-welding of Tools. — When it is desired to save small pieces of high-speed steel, a spot-welding machine may be used

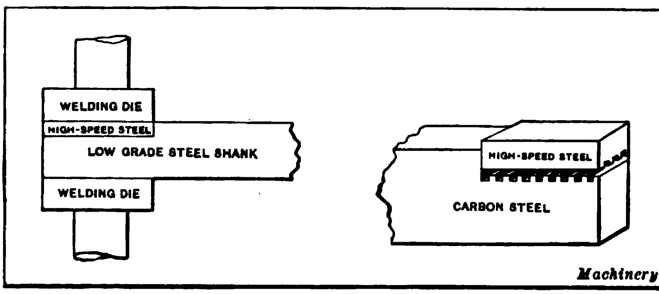


Fig. 31. Position of Parts to be welded relative to Welding Dies

Fig. 32. Grooving High-speed Steel Bit and Carbon Steel Shank for Welding

instead of a butt-welding machine. When the spot-welding method is used, the steel is shaped as shown in Fig. 29. The welds are made between two flat dies in either a spot-welding or a butt-welding machine, as shown in Fig. 31. If the stock is grooved, as shown in Fig. 32, it is easier to weld the flat surfaces. Any manufacturer can quickly determine whether the extra work of milling the pieces would prove profitable for his particular requirements or not. When welding small pieces of high-speed steel to low-carbon steel stock, the best results are obtained when dimension *A* in Fig. 29 is one-third and dimension *B* two-thirds of the total thickness. This proportion causes the greatest heat to be generated at the junction of the two pieces.

If dimension B is made proportionately larger, the hottest point will be below the junction of the pieces, resulting in the upsetting or blowing out of the stock, as shown in Fig. 33. If it is necessary to have B greater than the proportion given, a special copper die can be used which will clamp the low-grade stock as shown in Fig. 34. When this is done, dimension B is kept in the proper relation to the thickness of the high-speed steel. In all cases it is necessary to have the surfaces F and H of the parts, Fig. 35, absolutely clean and free from oil, dirt, rust, or scale. The surfaces where the copper dies make contact should also be clean and parallel. It is necessary to shape the pieces and have

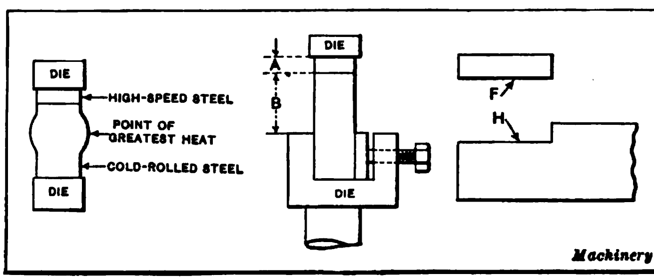


Fig. 33. Result of Improper Proportioning of High-speed and Low-carbon Steel

Fig. 34. Die for Equalizing Heating Effect of Disproportioned Steel Stocks

Fig. 35. Surfaces to be welded that must be freed of Rust, Scale, and Oil

their meeting faces perfectly smooth and level in order to obtain the best results. The current must be applied long enough to bring the metal at the joint to a welding temperature, and sufficient pressure must be applied to secure a perfect union at the joint. Spot-welding machines with the toggle joint in the head are particularly well adapted for this service, as they give an almost unlimited pressure when the toggle is straightened out to give the final squeeze, but the work can be done equally well with a butt-welding machine. A spot-welding machine applied to tool-welding is shown in Fig. 36. Welds made by spot-welding can be ground to any desired shape, but they cannot be forged after the weld is made. They do not require the heat-treatment

called for when a butt-weld is made, but they should be dropped in an oil bath or rapidly cooled as soon as the weld is completed.

In the foregoing, the welding of lathe and planer tools and drills has been chiefly dealt with, but it will be apparent that

Fig. 36. Spot-welding Machine welding High-speed Steel Insert to a Lathe Tool. At a Current Cost of Three Cents per Kilowatt-hour, the Cost should not exceed $3.00 for Welding 800 Pieces of 1/2- by 1/2- by 2-inch High-speed Steel — a Day's Work

these processes may be used for welding many other articles, as, for example, shanks to end-mills; and the cutting edges of chisels and similar tools may be made of good tool steel, and welded to a cheaper body with a consequent saving in cost. A great many other tools, such as small punches, taps, reamers, etc., may also be welded in a similar manner.

Hub and Spoke Welding Machine. — An electric welding machine of a special type, particularly adapted to the welding of hubs and spokes for agricultural machinery wheels, is shown in Fig. 37. In this machine, two wrought-iron hubs with spokes

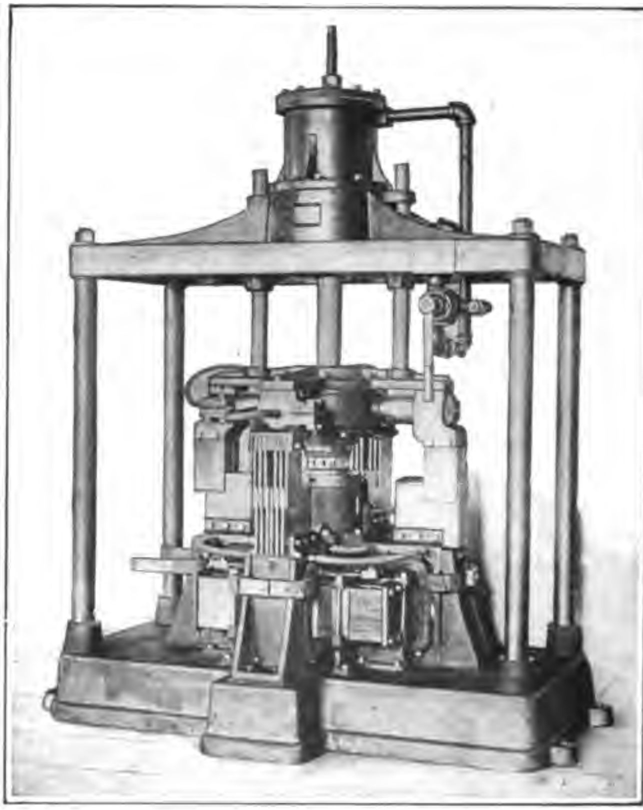


Fig. 37. Hub and Spoke Welding Machine designed by the Thomson Electric Welding Co.

inserted before being brought to the machine are welded together. This machine possesses some interesting points in its construction, especially as regards the relation of the terminals or contact points, which are secured through copper leaves that interlace or lock when the press is in operation. Power for operating this machine is secured through a hydraulic cylinder

located at the top, which is operated by the lever shown in front of the machine. In operation, the upper contact part of the machine is raised, leaving sufficient space so that the assembled hubs and spokes can be placed in the lower contact die. Then the lever at the front of the machine is operated and the hydraulic pressure forces the upper die down in contact with the work, and at the same time brings the copper leaves into contact with each other. The circuit is then closed and the hubs and spokes that are in contact immediately commence to heat. In about thirty seconds they reach a welding heat, when the pressure cylinder is again operated and the spokes and hubs are mashed together in one homogeneous mass. The wheel is then taken out and the outer rim placed on it.

Vertical Butt-welding Machine. — A special bench butt-welding machine of the vertical type for welding platinum tips to screws, etc., is shown in Fig. 38. In this machine, the welding electrodes or clamping dies are placed vertically instead of horizontally, as is the usual construction in butt-welding machines. This machine comprises a core *A* and secondary casting *B*; *C* and *D*, respectively, are the upper and lower terminals of the secondary casting. The lower terminal carries the anvil-like electrode *E* on which the disk of platinum is placed, this being retained in a holder which is adjusted by the screws shown. The upper terminal of the secondary casting carries a slide *F*, kept down by spring *G* working against plate *H*, through which the slide-operating rod *I* passes. Rod *I* is raised by rocker lever *J* which is actuated by chain *K* attached to a foot-treadle on the floor. This is so arranged that, when it is pressed down, the chain is pulled down, causing the forward end of the rocker lever to rise and lift slide *F*. Spring *L* is interposed to provide a continuous pressure on lever *J* when the foot-treadle is depressed; spring *M* keeps the forward end of lever *J* down. Attached to the lower end of slide *F* is a clamp *N* consisting of a horizontal rocking lever, to the forward end of which one of the clamping jaws is attached. Facing this jaw is another that is attached to the extreme bottom of the slide by a nut *O*. These jaws are bored out to suit the diameter of the screw to which

the platinum disk is to be welded. The horizontal moving lever is clamped by a cam on which P is the operating handle.

The switch-operating mechanism comprises upper contact arm Q pivoted on the same pin as lever J, but operated independently; R is the lower contact of the switch and is attached

Fig. 38. Special "Thomson" Electric Welding Machine built for Welding Platinum Tips to Screws, etc.

to lever J, whereas S and T are, respectively, the upper and lower contact levers of the break-switch. This break-switch is operated through the lever mechanism shown by the screw in slide F that comes in contact with lever U to trip the mechanism. In operation, slide F is raised slightly to allow the screw to be inserted, which is clamped by operating lever P. The platinum disk is then laid in a slight depression in electrode E. Slide F

is now lifted far enough to cause the block on arm *V* to strike block *W*, depressing contact lever *S* sufficiently to bring the contacts on the ends of levers *S* and *T* together, and at the same time causing the plate on projecting arm *Y* to catch on the plate on the end of lever *U*. The slide is now lowered by raising the foot from the treadle; this brings the screw in the clamping jaws in contact with the platinum disk. Upon further raising of the treadle, the forward end of lever *J* tips down under the pull of spring *M*. The closing switch attached to lever *J* is thus raised, closing the circuit, when fusion between the screw and disk immediately takes place. As fusion progresses, there is a slight upsetting of the material due to the pressure of the spring, so that slide *F* moves downward an amount equal to the upset. Tripping screw *Z* now strikes lever *U*, causing it to be disengaged from the plate on arm *Y* of lever *S*. This allows lever *S* to fly up and thus break the circuit. The weld is now complete, and cam lever *P* is pushed back to release the screw, whereupon another screw and disk are inserted and the operations are repeated.

The preceding gives some idea of the many types of electric welding machines built, and shows some of the possibilities of electric welding. Some machines are built to operate semi-automatically, whereas others are built so that it is only necessary to place the work in the machine. Various arrangements are also used for operating the movable head and other movable members of the machine, depending upon the requirements. On the smaller sizes, the movable head is operated by a lever, by hand or power, and on the larger machines hydraulic pressure is used. The construction and operation of the machine depend largely upon the shape and nature of the work to be welded.

CHAPTER III

ELECTRIC SPOT-WELDING

ELECTRIC spot-welding consists in forcing sheet metals together by means of copper electrodes and heating the metal through the same medium. There is a limit to the thickness of sheet metal that can be satisfactorily spot-welded: First, the copper rods used for the electrodes will only carry a certain amount of current without excessive heating, and when the current required to make the weld exceeds the capacity of the electrodes, the latter will soften and wear away rapidly; second, to produce a satisfactory spot-weld, it is necessary to have the two pieces of sheet metal touch each other at the point where the weld is to be made. When the pressure required to bring the opposing sheets of metal into contact exceeds the compressive strength of the electrodes, the ordinary spot-welding machine cannot be used. For work of this kind, other processes, which are given different names because of the variations in application, are used. One method is to enclose the copper electrodes in hardened steel bushings. The bushings and heating electrodes are operated by separate mechanisms, and to effect the weld the bushings are first operated to bring the sheets into contact, after which the current is turned on and the weld made.

Difference between Butt- and Spot-welding. — Electric spot-welding differs from electric butt-welding in that the parts being welded do not necessarily need to be of the same cross-sectional area, and the parts can be welded at one point or at a series of points by forming contact points of the required area upon the faces of the upper and lower electrodes. In the butt-welding machine, the work is held in clamping jaws of varying shapes to suit the work; these jaws are made from copper and serve as electrodes. In the spot-welding machine, round rods of copper are used for the electrodes, and as they are presented with their

contacting points opposing each other, they localize the current at the point where the weld is to be made. As is the case with butt-welding, a large volume of current at low voltage is made to pass through the electrodes, and when two pieces of sheet metal are placed between these points, and the current turned on, the metal instantly becomes hot at the point where the copper electrodes touch it. The hotter the metal becomes, the greater the resistance. The sheet metal between the electrodes is, therefore, rapidly brought to a welding temperature, and a slight pressure of a lever forces the molten metal together and forms a perfect weld at the point of application of pressure.

Electric Spot-welding Machine. — An electric spot-welding machine consists essentially of a transformer for reducing the current from a high to a low voltage, a secondary circuit for conducting the current from the transformer to the welding electrodes, and the welding electrodes or copper contact points for localizing the current and applying the pressure. The constructional features of the various spot-welding machines differ to a considerable extent, depending upon the kind of work for which the machine is designed. The principle, however, upon which these machines are constructed is the same. Fig. 1 shows a common type of spot-welding machine; the main body of the machine is of the hollow column type to which an overhanging top arm is cast. Working in this arm is a slide which can be operated either by a toggle lever or foot-treadle, as desired. Fastened to the column is a lower arm or holder which carries the lower electrode. A series of laminated copper strips connect the electrode and the transformer. These strips are attached to the electrode holders by bolts, and the upper laminated strips are so constructed as to permit movement of the slide. The transformer proper is so constructed that the amount of current passing through the winding and, hence, the amount induced in the secondary circuit can be varied. Two pointers are located on the column of the machine, one working on the segment of a dial having two positions, "low" and "high," and the other covering a segment numbered from 1 to 5.

In setting a spot-welding machine, the upper regulator pointer

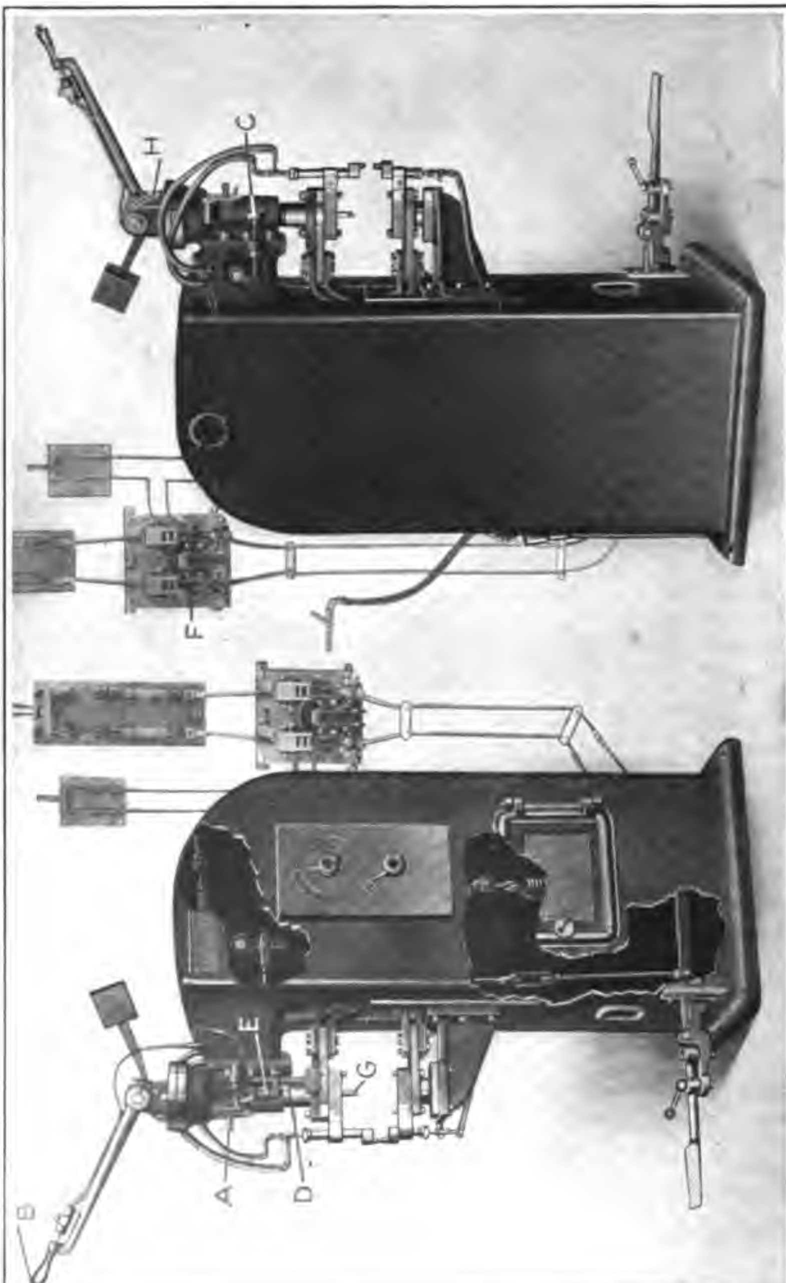


Fig. 1. Common Type of Electric Spot-welding Machine sectioned in Certain Places to show Constructional Features

should first be set to 1, and the lower regulator pointer to the left marked "low." The work is then placed between the copper electrodes, and these are brought down in contact with it; this forces the stock together and automatically turns on the current. If the stock does not heat rapidly enough, the upper regulator pointer is turned to 2, and this process is continued until the pointer reaches 5. If there is still insufficient current to heat the work quickly enough, the upper regulator is turned back to 1 and the lower pointer placed at "high." The same procedure is then followed by moving the upper pointer from 1 to 5 until the proper temperature is obtained. The electrodes should be adjusted with two pieces of stock between them so that the toggle joint in the head of the machine stops just forward of the center in order to give the greatest amount of pressure on the stock.

In this particular machine, the switch can be operated either automatically or by hand for turning the current on and off. When welding thick buckled stock, it is difficult to obtain a satisfactory weld by using the automatic switch, because of the variation in pressure required to force the opposing faces of the sheets together. When the stock is in a buckled condition, pin *A* is placed in the right-hand slot, which disconnects the automatic switch. To operate the machine, the lever or foot-treadle is moved as far as possible to bring the material into contact. The button *B* or control switch in the handle is then depressed and this turns on the current.

In using an electric spot-welding machine continuously, the copper electrodes become heated, and, in order to increase their life, a water cooling system is provided. The holders which carry the welding electrodes proper are made hollow, and through these a tube passes, allowing water to circulate close to the welding contact points. Each pair of electrodes is provided with a water supply and return pipe.

Operation of Spot-welding Machine. — The operation of an electric spot-welding machine differs from that of a butt-welding machine in that, as a rule, no clamping of the work is necessary on the spot-welder. The two sheets to be joined are simply held in the hands in the correct position and in the proper location in

relation to the copper electrode points. When this is done, the operator simply pulls down the lever or operates the foot-treadle. When the automatic switch is closed, this allows the current to pass through the contact points, and the material placed between them immediately becomes heated. When the proper temperature has been obtained, pressure is applied to effect a junction between the two sheets being welded. In order to obtain the correct pressure between the sheets, the electrodes should be adjusted. This can be done by loosening the clamps and raising or lowering them to the most convenient position. Before making any adjustment, the wall switch should be opened. The bolts fastening the copper leaves to the transformer and the copper electrode holders should be carefully tightened after the machine has been submitted to severe usage. The sliding head should be well oiled and the grooves kept clean. The movement of the electrodes or the up-and-down movement of the foot-treadle or hand lever is adjusted by means of screw *C* located on the front of the machine, which comes in contact with a dog connecting the foot-treadle or hand-operating mechanism.

Welding Processes on Spot-welding Machines. — The electric spot-welding machine, in addition to being used for spot-welding sheet metal, can also be used for a variety of other processes. In electric spot-welding practice, the copper electrodes are used to fuse the two sheets of metal together at localized points. The action which takes place is clearly indicated at *A* in Fig. 2. Before making the weld, the two electrodes are brought into contact with the sheets. In making the weld, the upper pointed electrode is depressed into the upper sheet, as shown, and the two sheets welded together at the point indicated by the double cross-hatching.

Point-welding. — At *B* is shown the method of welding known as "point-" or "projection-welding," which differs from spot-welding in that the material must be provided with projections. These projections are brought into line with each other, and when the electric current is applied, the resistance, being greatest at the contact points, causes them to quickly reach a welding tem-

perature, and upon the application of pressure the two sheets are welded at the points in contact.

Ridge-welding. — At *C* is shown another application of the spot-welding machine. In this case it is used for making what is known as a "ridge-weld." This requires previous preparation of the material, which is placed, as shown, between the electrodes with the ridges forming a cross. In this case, the electric current is also confined to the spot where the contact is made, and when

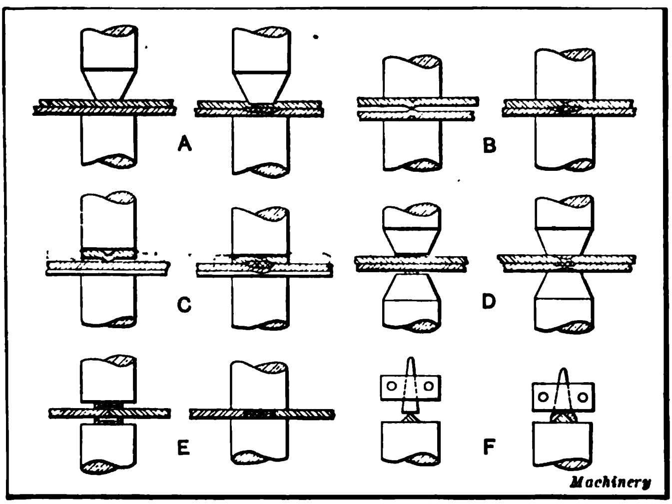


Fig. 2. Diagram illustrating Various Processes of Electric Welding accomplished on Electric Spot-welding Machines

the current is turned on and pressure applied, the metals are welded together.

Button-welding. — Still another application of the spot-welding machine is indicated at *D*. This process is known as "button-welding," because of the practice of using one or more "buttons" to localize the current. This is particularly advantageous for welding thick sheets that cannot be brought into intimate contact by the copper electrodes. In this case the buttons or disks of metal are interposed between the opposing faces of the electrodes and the pieces to be welded; these disks localize the current, causing the metal to quickly reach a welding temperature.

Upon the application of pressure, the highly heated buttons are pressed into the sheets and form a solid junction. There are many applications of this method, some of which will be described later.

Bridge- or Tie-welding. — The process of welding shown at *E* is known as "bridge-" or "tie-welding," because of the shape of the parts used to unite the two sheets. In a sense, this method could be called "butt-welding," because the two sheets being welded are butted together, a junction being made between them by employing two channel-shaped pieces which overlap the ends of the sheets. When the electrodes are brought in contact with the work and the electric current turned on, these two pieces localize the current and offer sufficient resistance to cause them to heat; then, upon the application of pressure, they are forced into intimate contact and become one with the pieces to be welded.

Tee-welding. — Another process that is used quite extensively in the agricultural implement industry is shown at *F* in Fig. 2. This method is known as "tee-welding," and is shown applied here to the manufacture of garden rakes. The same principle is employed as in the case of point-welding. The back or frame of the rake is made with a knife edge, and in this way localizes the current, so that sufficient resistance is offered to the flow of the electric current to fuse the metal and allow the prong to be forced over the back of the rake and united with it. There are many different applications of the principles described in the foregoing, some of which will be illustrated later.

Materials that can be Spot-welded. — As the satisfactory welding of two pieces of metal depends upon their relative resistance to the flow of an electric current, such metals as copper, silver, aluminum, etc., are difficult to spot-weld. The reason for this is that they offer no more resistance to the flow of the electric current than the electrodes themselves, and hence difficulty is encountered in obtaining a welding heat. Pure aluminum cannot be commercially spot-welded, but by the addition of a small percentage of iron, or 20 per cent of zinc, satisfactory welding is possible. Galvanized iron can be welded, although it will burn

off the zinc at the spot where the weld is made, and this method is not recommended for welding very thin galvanized iron, as there is no body of metal to work on; 28-gage (0.0156 inch thick) galvanized iron and heavier can be welded without difficulty. When the galvanized iron sheets are very thin — below 0.015 inch — the button method of welding can be used to advantage.

Cast copper can be electrically butt-welded to steel, brass, sheet copper, wrought iron, and galvanized iron, but the surface of the cast copper becomes crystallized to a considerable extent when spot-welded, and, therefore, this method is commercially impracticable for spot-welding. Sheet steel or brass cannot be commercially electrically welded to cast iron, because cast iron is usually very impure and the section at the weld becomes crystalline in structure. Tin can be welded to tin or to sheet iron, but the stock will be discolored at the weld. Sheet brass and bronze can be welded to sheet brass or to sheet steel. Experience is required in this kind of work for determining just what pressures and temperatures are necessary, and the automatic switch must be very accurately set.

Alloys containing tin are very difficult to spot-weld, bronze welded to aluminum being particularly so. These alloys are affected with what is known as "tin" disease. Bronze welded to aluminum will hold together for a short while, but soon becomes disintegrated. In fact, a weld can be successfully made in bronze and aluminum, and shortly after the weld has been made the joint will be strong, but after being exposed to the atmosphere for twenty-four hours or more, the metals can easily be pulled apart again.

German silver, monel metal, zinc, nickel and alloys of many kinds are easily welded. In some cases it requires a special preparation of the material, or various shapes of electrodes, and in some cases it is necessary to change the transformer in the machine, in order to obtain a heavy current over a short period of time. Malleable iron of good quality can be welded to sheet steel, but it will not stand as great a strain as rolled steel or iron. In welding heavy gages of sheet steel where the material is badly buckled, the adjacent surfaces cannot be brought into con-

tact by means of the electrodes. In cases of this kind the foot pressure used to force the uneven surfaces together would trip the switch before a weld could be made. To take care of this condition, a hand-operated switch *B*, Fig. 1, is brought into use, as previously described. With this device it is possible to do work that could not be done with the regular automatic switch.

Relation of Time to Current and Pressure in Spot-welding. — There are four vital points that must be taken into consideration in making a satisfactory spot-weld. They are: 1. Condition of stock, whether pickled, oxide-coated, coated with zinc, lead, etc. 2. Time required to make the weld. 3. Pressure on the electrodes, which should bear a direct relation to the current used and the time taken to make the weld. 4. Amount of current passing through the secondary circuit. An increase in the pressure necessitates an increase in the amperage of the current; and the lower the amperage, the greater the length of time required to complete the weld, and *vice versa*. As the thickness of the stock increases, the pressure and current should be increased. Using a small current and heavy pressure will not give a perfect weld, and a heavy current and low pressure will burn the metal. For example, suppose the metal to be welded is $\frac{1}{16}$-inch thick pickled sheet steel. The pressure should be 200 pounds, the current, 10 kilowatts, and the time, one second. This will give a perfect weld, if the electrode points are properly shaped. In welding an oxide-coated stock, the usual practice is to increase the pressure over that required for welding pickled stock. In welding $\frac{1}{16}$-inch thick steel, having a scaled or black hot-rolled surface, the pressure would be increased from 50 to 100 per cent, or to 300 or 400 pounds, the current, from 10 to 12 kilowatts, but the time would remain one second. In welding a zinc-, lead-, or aluminum-coated stock, the pressure and time should be decreased. For example, in welding $\frac{1}{16}$-inch thick aluminum-coated steel, the pressure should be from 100 to 150 pounds, the current, 10 kilowatts, and the time, $\frac{3}{4}$ second.

Determining Pressure Required. — To determine the pressure required to make a satisfactory spot-weld, a regular platform scale is placed in front of the electric welding machine in such a

position that a bar can be placed between the upper or movable member of the machine and the platform. Experiments are then made on small pieces of sheet metal of the same thickness as that to be welded until the required pressure, time and current have been determined. As has been previously mentioned, the amount of current can be controlled by moving the regulator pointers. The correct pressure, however, is more difficult to determine. To be certain that the welded joint is satisfactory, a section of the metal should be polished, and a microscopic examination made.

The way in which the necessary adjustments are made can be seen by referring to Fig. 1. For regulating the time that the current is on, screw *D* is adjusted. Turning this screw to the right shortens the time, and turning it to the left lengthens the time. This screw controls the position of automatic switch *E* which operates the solenoid switch *F*. To vary the pressure on the work, screw *G* is adjusted. This screw is loosened for light work, and tightened for heavy work. In addition to obtaining the proper adjustment for time, pressure and current, the electrode points should also receive attention. In the first place, the points should be properly shaped, the correct shape depending upon the material to be welded, as will be subsequently described. For welding pickled steel, the electrodes should be so set in the holders that, when the two pieces of metal are placed between the contact points, the toggle joint *H* in the head of the machine stops just forward of the center. In welding brass, galvanized iron, tin, terneplate, German silver, aluminum, sherardized steel, and all coated materials, it is advisable to use less pressure between the electrode points. This can be done by setting toggle joint *H* forward to a more acute angle and loosening the tension on the compression spring by adjusting screw *G*.

Shape of Electrode Points. — In spot-welding sheet metal, various shapes of electrode points are used. In most cases, the shape is governed either by the kind of material being welded or the position in which the weld is made. For welding sheet steel to sheet steel, the lower electrode point is generally left flat or slightly convex, as shown by the dotted line at *A* in Fig. 3,

whereas the upper electrode point is pointed, the diameter of the point varying with the thickness of the sheet, as shown in Table I. In welding tin-, lead-, or zinc-coated iron, both the upper and the lower electrodes are pointed. The reason for this is that coated stock is more difficult to weld than uncoated material, and the aim is to confine the weld to as fine a point as possible to obviate burning. The shape of the electrode point should receive careful attention for several reasons. An im-

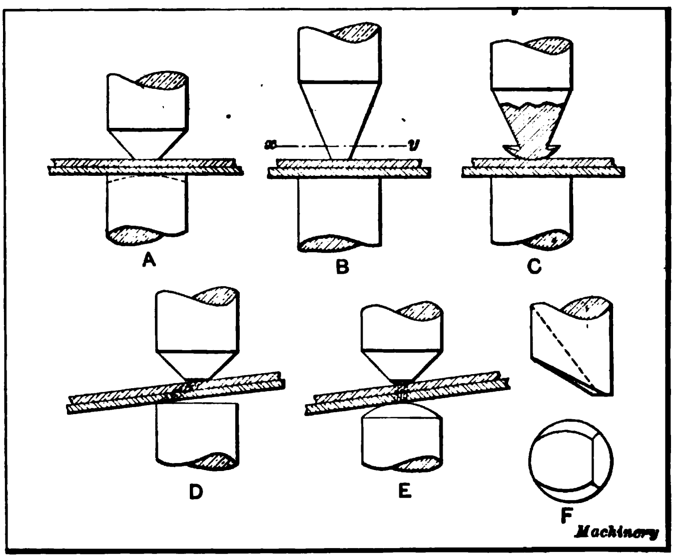


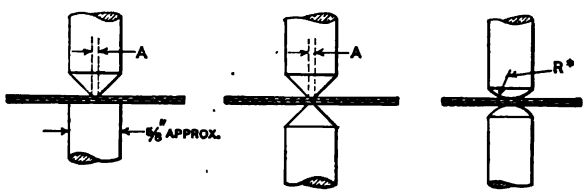
Fig. 3. Shape of Electrode Points used on Electric Spot-welding Machine for Various Purposes

properly shaped point will not last nearly as long as one that is properly shaped, and it will not produce a satisfactory weld.

Many machine operators make the point of the electrode too long. Reference to *A* and *B* in Fig. 3 will make this clear. Here the electrode at *A* is correctly shaped, lasting considerably longer and producing better welds than the point shown at *B*. The point shown at *A* has much more body and will withstand greater pressure without upsetting than the point at *B*. The reason for this is that, in using the point at *B*, the extreme end is made

hotter than the portion just back of it on the line xy, and, when pressure is applied, an upsetting action takes place because of the lack of resistance, causing the point to upset and flare, as shown at C. When the point is upset as shown at C, it will produce an unsatisfactory weld.

Table I. Diameter of Electrode Points Used in Welding Sheet Stock of the Same Thickness



No. of Gage, U. S. Standard	Thickness, Inch	Decimal Equivalent	Wrought Iron or Sheet Steel — Diameter of Point A in Inches	Galvanized Iron — Diameter of Point A in Inches
0	5/16	0.3125	7/16	....
1	9/32	0.2813	7/16	....
2	17/64	0.2656	7/16	....
3	1/4	0.2500	7/16	....
4	15/64	0.2344	3/8	....
5	7/32	0.2188	3/8	....
6	13/64	0.2031	3/8	....
7	3/16	0.1875	5/16	3/8
8	11/64	0.1719	5/16	3/8
9	5/32	0.1563	5/16	3/8
10	9/64	0.1406	1/4	1/4
11	1/8	0.1250	1/4	1/4
12	7/64	0.1094	1/4	1/4
14	5/64	0.0781	1/4	3/16
16	1/16	0.0625	3/16	3/16
18	1/20	0.0500	3/16	3/16
20	3/80	0.0375	3/16	1/8
22	1/32	0.0313	1/8	1/8
24	1/40	0.0250	1/8	....
26	3/160	0.0188	1/8	....
28	1/64	0.0156	1/8	....

* For electrodes 5/8 inch in diameter, radius "R" varies from 3/8 to 1/2 inch.

The remarks just made apply more particularly to the upper electrode, which is generally pointed for welding all materials, but they also apply to the lower electrode when the latter is used for welding coated stock. When pickled sheet steel is welded,

the lower electrode is not pointed, but is generally made flat. When large articles are spot-welded, it is better practice to make the lower electrode slightly convex instead of flat. The reason for this is that it is difficult to hold large articles so that the surfaces are in perfect contact with the flat face of the electrode. If the work is not properly located, as shown at *D* in Fig. 3, a scar will be produced on the lower surface of the work. This is caused

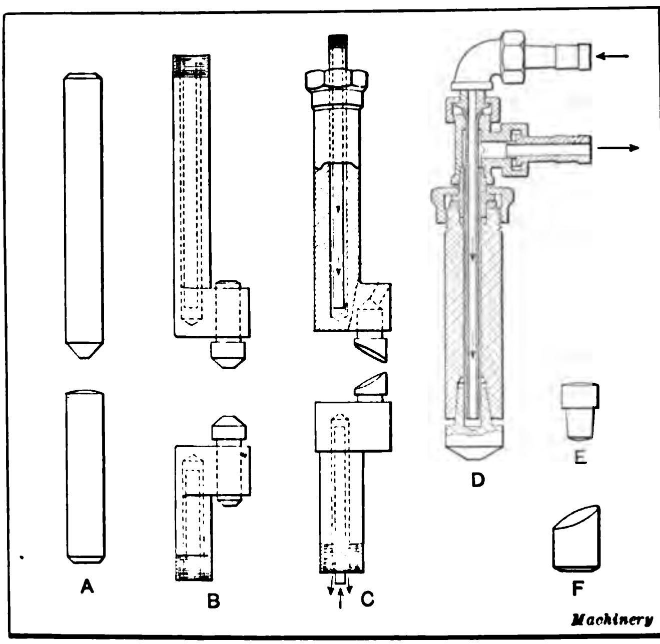


Fig. 4. Method of holding and cooling Electrode Points on Electric Spot-welding Machines

by the work bearing on one edge of the lower electrode only, and the current, instead of flowing straight or following the axes of the electrodes, shoots off at an angle, and, in most cases, produces an unsatisfactory weld. The diagram at *E* shows what takes place when the lower electrode is slightly convex and the work held at an angle. Although the work is not held correctly, it does not produce an imperfect weld, as a point instead of a "line" contact is secured.

The electrode point shown at *F* is used for getting in close to the edge of a box or corner. The point shown by the full lines will last much longer and make a better weld than the point indicated by the dotted line, because it will withstand a greater pressure without upsetting.

Holding and Cooling Electrode Points. — Electrodes for spot-welding machines are generally made from round bars of copper of about from $\frac{3}{4}$ to $1\frac{1}{2}$ inch in diameter when of the solid type, and smaller ($\frac{5}{8}$ inch in diameter) when of the inserted type. As illustrated in Fig. 4, those shown at *A* are known as the "solid" type, and are held in water-cooled holders, whereas those shown at *B* are of the inserted type or tip construction, and are held in water-cooled holders by means of a shank as illustrated. The holders carrying the electrodes are connected by a $\frac{1}{2}$-inch water pipe and a flexible pipe to a water main; this pipe supplies enough water to keep the electrode points fairly cool; the return pipe is connected with the sewer.

The illustration at *C* in Fig. 4 shows how this connection is made. The inner pipe carries the water into the holder, and it returns through the space between the hole in the holder and the inner pipe. This type of holder does not carry the cooling effect direct to the electrode point, and, therefore, is not as effective as the holder shown at *D*. Here the electrode tip is inserted directly into the holder and is drilled out for the insertion of the cooling pipe, which can be brought almost to the end of the electrode. The arrows indicate the direction in which the water flows. At *E* and *F* are shown two types of electrode points. The one shown at *E* is used for welding average stock; the one at *F* is used for welding near corners. There are many different types and shapes of electrode points in use, but those shown in the illustration represent some of the more common kinds.

Electrode Holders. — The type of electrode holder used on a spot-welding machine is governed almost entirely by the kind of work to be welded. There are, however, several standard types of holders which are capable of being applied to a large class of work. The holder shown at *A* in Fig. 5 is known as the heavy-duty machine type of holder. It is rigidly constructed and is

provided with a solid type of electrode, the cooling pipes being connected directly to the holders themselves. Another type of standard holder is shown at *B* in Fig. 5. This type of holder is used for semi-heavy stock and is principally adapted for electric welding operations where it is necessary to come close to a corner. The electrode points are so shaped that the welding can be done at the extreme edge. The construction of this holder does not differ materially from that shown at *A*, except that it is not as heavily and rigidly built.

Several forms of electric welding machine holders, commonly known as "horns," are shown in Fig. 6. The type of horn shown

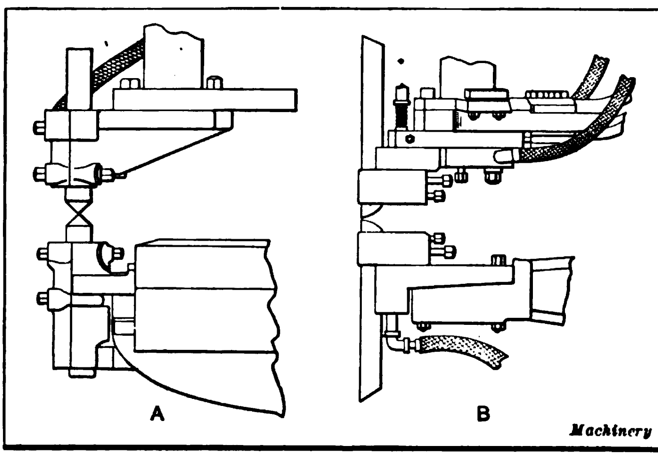


Fig. 5. Two Types of Electrode Holders

at *A*, which carries bent upper and lower electrode points, is used for such work as the welding of automobile muffler tubes, where it is necessary to make the weld at some distance from the end of the tube. The type of electrode horn shown at *B* is of a somewhat similar construction, but is much more effective for constant use, as it is possible to bring the cooling pipes or water slightly closer to the point where the welding is done. When the welding machine is used continually, this is a factor that must be considered. The type of electric welding horn shown at *C* is of unusual construction; the lower electrode instead of the upper

one is pointed. This horn is used for welding a plate onto a channel, as illustrated. The horn shown at *D* is of rather unusual construction and is chiefly employed when it is necessary to use a small electric welding machine for welding large, thin work. The arrangement increases the capacity of the machine between the column and the electrode points.

Fig. 7 shows two applications of electric welding machine horns. At *A* is shown a type of horn which can be used for welding along

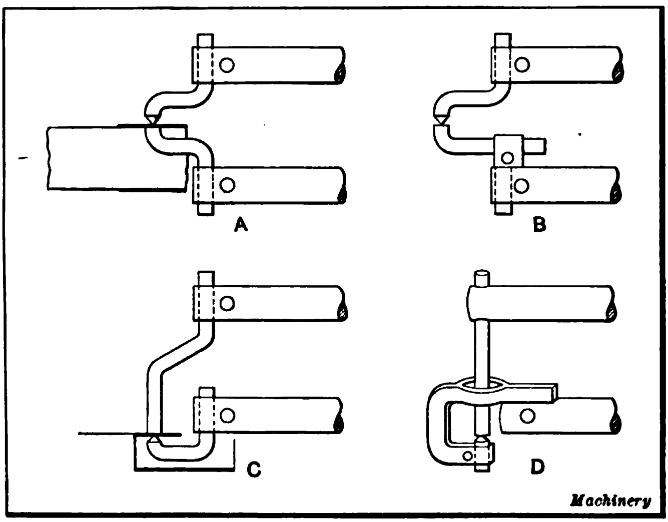


Fig. 6. Diagram illustrating Several Different Types of Electrode Horns

the corner of a box, one of the electrode horns extending into the box and the other working on the top edge. The type shown at *B* is of slightly different construction, in that the welding, instead of being done in a position extending out from the machine, is done in a horizontal position in the machine, and makes necessary the use of an extended lower electrode holder.

Spot-welding Fixture. — An electric welding operation of more than ordinary interest is employed in welding electric starting and lighting outfits for automobiles. The operation consists of spot-welding a German silver relay contact to its brass holder.

Fig. 8 shows the sheet metal parts separately and as they appear after making the two spot-welds necessary to join them. The parts must be located squarely before welding, and the holes in the two pieces must be in line. The fixture for holding the work

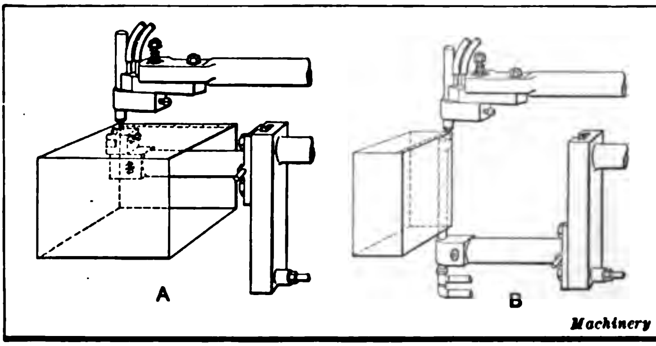


Fig. 7. Diagram illustrating Two Different Types of Electrode Horns for Welding Boxes

was designed to meet these conditions, and as it is not practicable to make two spot-welds simultaneously with one pair of electrodes, provision had to be made for moving the work to make the two welds separately. The fixture is shown in Fig. 10; it is of the swiveling type. The first and second positions occupied in

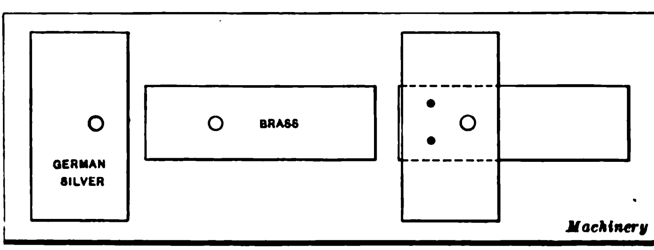


Fig. 8. Parts to be welded

making the welds are shown in full and dotted lines, respectively. The brass brush-holder is first dropped into a shallow slot in the fixture, the rear end resting against a shoulder. The German silver part is next laid over the brass part and at right angles to it. The operator now presses down the spring locating pin that

centralizes the parts and lines up the two holes. As soon as the finger pressure on the locating pin is released, it springs up out of the way until needed for the next piece. The foot-lever of the welding machine is depressed to make the first weld. The fixture is then swiveled to bring the second welding point into position under the electrodes, and the second weld is made, completing the job very rapidly.

Preparation of Work for Spot-welding. — In welding sheet metal, the best results are obtained when the stock is clean and

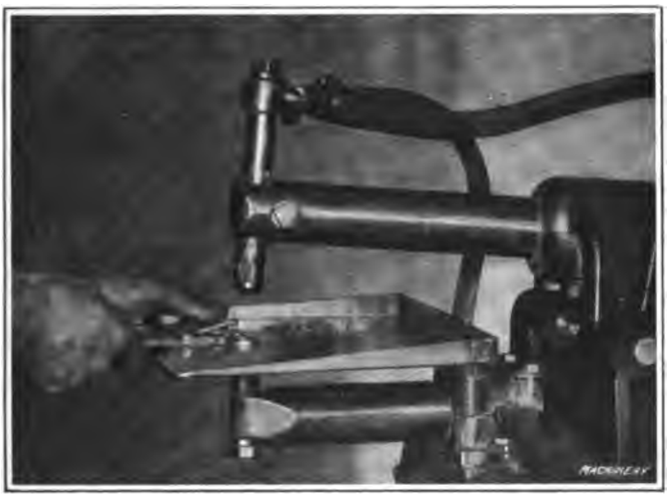


Fig. 9. An Example of Spot-welding

free from scale, rust, or dirt. The cleaner and better the stock, the easier it is to weld, and the less current it takes to do the work. It will also be found that when the metal is clean and free from scale the electrodes will wear much longer than when the stock is dirty. Electrodes should be kept clean and firmly held in their holders. If dirt is allowed to gather around the sockets that hold the electrodes, good contact cannot be made. Dirt and grease as well as scale are non-conductors of electric current, and with the low voltage employed in electric spot-welding machines, it takes very little dirt, grease, or scale to prevent a good contact and to produce poor results. In fact, the entire machine

should be kept clean, and if there is undue heating at any point, it is a clear indication that there is poor contact, and this should be remedied without delay. Loose joints in the machine mean that there is poor contact and resultant heating. Care should be taken to see that the bolts fastening the copper leads or secondary circuit of the transformer and the copper blocks holding the electrodes are tightened.

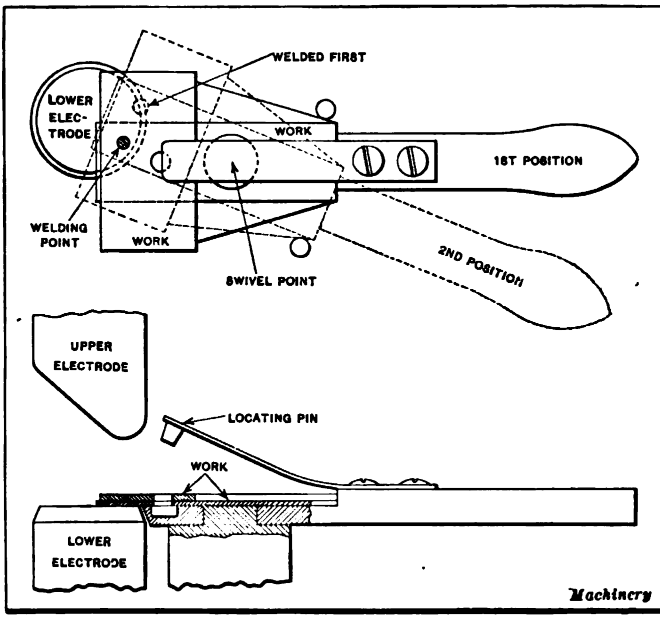


Fig. 10. Details of Welding Fixture

Welding processes other than spot-welding which can be accomplished on a spot-welding machine require in most cases a previous preparation of the stock. Some of these processes are known as "point-welding," "bridge-welding," "tee-welding," etc. The methods used in preparing the stock for these various processes will be described later.

Power and Time Required for Spot-welding. — The power required for operating an electric welding machine depends upon the size of the machine, character and thickness of the material

being welded, and the time taken to make the weld. In operating all electric welding machines of the resistance type, alternating current should be used of either 220 or 440 volts, 60 cycles. Where the frequency varies from 60, a special transformer is necessary. Voltages higher than 450 — up to 550 or 600 — are more dangerous to handle, and it is advisable to use a remote control switch mounted on the wall at some distance from the machine. This prevents any possibility of the operator coming in contact with the high-voltage current when operating the welding machine. Where multiphase current is available, only one phase of the system should be used. Inside the welding machine, and forming a part of it, is a transformer which transforms the voltage of 220 or 440 down to three or five volts, which is the pressure used in all "stock" machines for making the average weld in sheet metal. This voltage is so low that it cannot be felt by the bare hands, and explains why it is absolutely safe for the operator.

Table II gives the approximate amount of power required for welding a given thickness of sheet steel in a given time. This can be varied at will, as the time can be shortened by increasing the power, or the amount of power can be decreased by taking a longer time to do the work. In the table, the cost for current is based on one thousand welds at a cost of one cent per kilowatt-hour. To obtain the approximate cost of welding various thicknesses of stock, multiply the price given in the last column by the rate per kilowatt charged by the local electric light company, which will give the cost of current per one thousand welds. For example, suppose the material being welded is $\frac{1}{16}$-inch sheet steel. The power required would be 12 kilowatts, time 0.85 second, and the cost per one thousand welds, figuring on a basis of eight cents per kilowatt-hour, would be $2.84 \times 8 = 22.7$ cents.

Strength of Spot-welded Joints. — One of the chief advantages of electric spot-welding is that it takes the place of riveting on many classes of work, and not only does the work more rapidly, but also more effectively. For instance, an electric spot-welded joint is stronger than a riveted joint. The examples shown in Fig. 11 give some idea as to the efficiency of a welded joint as compared with one that is riveted. The data pertaining to these

tests are as follows: The strip *A* was spot-welded in one place and broke at the weld when a pull of 1625 pounds was exerted on it. The strip *B* was spot-welded in two places and also riveted in two places. It broke at the riveted joint when a pull of 1555 pounds was reached. The strip *C* was spot-welded in three places

Table II. Time and Power Required and Cost of Spot-welding Sheet Steel and Iron

No. of Sheet Steel Gage, U. S. Standard	Thickness in Fractions of an Inch	Decimal Equivalent, Inch	Approximate KW. Required	Time in Seconds to Make a Weld	Cost of 1000 Welds at 1 cent per KW.-Hour
28	1/64	0.0156	4.0	0.25	$0.00278
26	3/160	0.0187	5.5	0.30	0.00458
24	1/40	0.0250	7.0	0.40	0.00774
22	1/32	0.0312	8.0	0.50	0.01110
20	3/80	0.0375	9.0	0.55	0.01375
18	1/20	0.0500	10.0	0.70	0.01945
16	1/16	0.0625	12.0	0.85	0.02840
14	5/64	0.0781	13.5	1.00	0.03750
12	7/64	0.1093	16.5	1.30	0.05950
10	9/64	0.1406	19.0	1.70	0.08950
9	5/32	0.1562	20.0	1.80	0.10000
8	11/64	0.1718	21.5	2.00	0.11950
7	3/16	0.1875	22.5	2.10	0.13100
6	13/64	0.2031	23.5	2.20	0.14350
5	7/32	0.2187	24.5	2.35	0.16000
4	15/64	0.2343	25.5	2.45	0.17300
3	1/4	0.2500	26.5	2.60	0.19100
1	9/32	0.2812	28.5	2.80	0.22200
0	5/16	0.3125	29.5	2.95	0.24100
000	3/8	0.3750	33.5	3.50	0.30800
00000	7/16	0.4375	36.5	4.00	0.40500
0000000	1/2	0.5000	39.5	4.45	0.48800
....	9/16	0.5625	42.2	4.90	0.57400
....	5/8	0.6250	45.0	5.40	0.67600
....	11/16	0.6875	47.7	5.84	0.77300
....	3/4	0.7500	50.7	6.30	0.88800
....	13/16	0.8125	53.5	6.80	1.01000
....	7/8	0.8750	56.3	7.25	1.13500
....	1	1.0000	62.0	8.20	1.41300

and broke outside the weld when a pull of 2715 pounds was exerted. The strip *D* was spot-welded in three places and also had three rivets. It broke at the riveted joint when a pull of 2055 pounds was exerted. The strip *E* was lap-welded and broke outside the weld when a pull of 2720 pounds was reached. Strip *F*

was butt-welded and broke at the weld when a pull of 2555 pounds was reached. Strip *G* was spot-welded and riveted in one place. It broke at the rivet with a pull of 990 pounds. Strip *H* was lap-welded and broke at the weld when a pull of 2425 pounds was reached. Strip *I* was spot-welded in two places and broke at the weld when a pull of 2275 pounds was reached. Strip *J* is a plain piece of the same stock, which was not welded, and broke when a

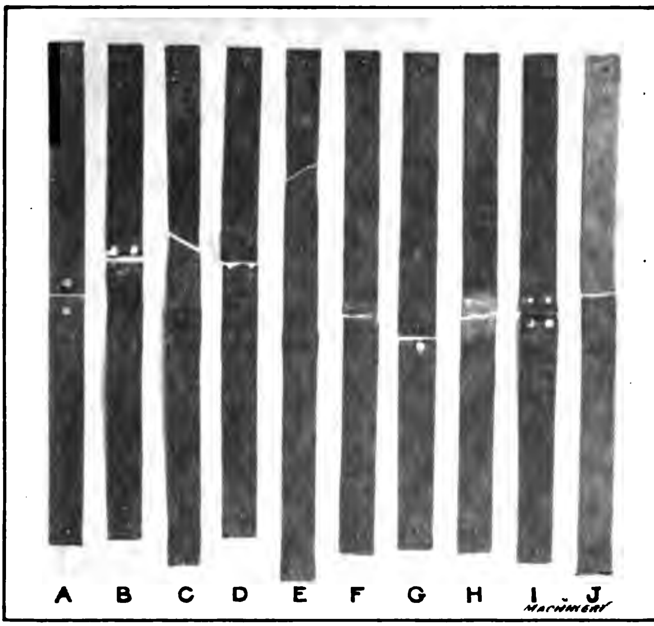


Fig. 11. Results of Tests made to show Comparative Strength of Spot-welded and Riveted Joints

pull of 2690 pounds was reached. It will be noticed that in all cases the electrically welded joints were stronger than the riveted ones.

Another example which illustrates the effectiveness of a spot-welded joint is shown in Fig. 12. In this case, two pieces of sheet steel of the same thickness have been spot-welded at one point. In endeavoring to separate these two pieces, the welded joint still held, and the metal around the weld gave way.

Riveting on a Spot-welding Machine. — There are certain classes of work where a rivet is desired. The rivet, generally, in small-sized work, is upset by a riveting machine. An electric welding machine can be used to good advantage on this work, however, because the rivet, instead of being closed over in a cold state, is heated by the electrodes of the machine, and hence makes a much better joint than if it were riveted over cold. Fig. 13 shows several different methods of performing electric riveting operations. At *A* is shown one method. Here the rivet is welded to the lower plate. The top plate is provided with a

Fig. 12. Results of an Endeavor to separate Two Pieces of Sheet Steel that have been spot-welded — Note how Metal around Welded Spot is tearing away and Welded Spot remains Intact, forming one Sheet with the Lower Piece

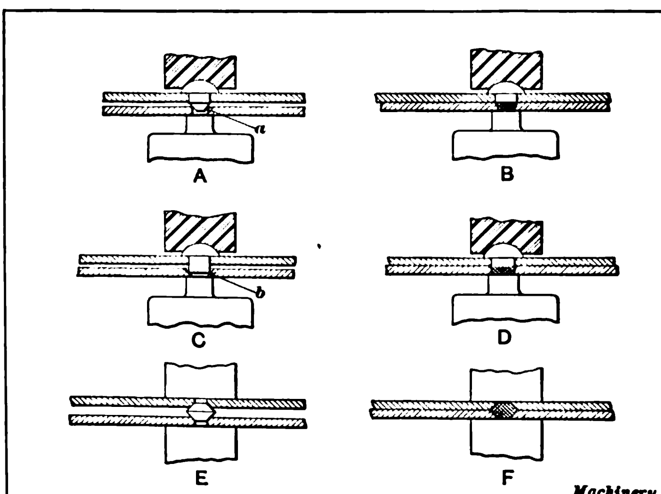


Fig. 13. Diagram illustrating Various Processes of accomplishing Electric Riveting on a Spot-welding Machine

larger hole than the bottom plate, and the rivet is pointed. Using a combination of this sort makes a very strong joint, because the heat is localized at the point *a* which, when the plates are pressed together, acts as a junction point. The result of a weld of this character is shown at *B*. Still another application of electric riveting is shown at *C*. In this case the lower plate is provided with a taper hole and the rivet with square corners. Again

Fig. 14. Electric Riveting of Cream Separator handled on an Electric Welder

the heat is localized in the lower plate at the point *b*, and a satisfactory weld can be made, as shown diagrammatically at *D*.

When it is desirable to have both surfaces of the plates smooth, the method shown at *E* can be adopted. Here a double-cone rivet is interposed between the two plates, which, as illustrated, are provided with holes equal in diameter to about the smallest diameter of the cone-shaped rivet. When the current is turned

on and pressure applied, the rivet is "fused" and forms a perfect junction between the two plates, as illustrated at *F*.

A practical application of electric welding is shown in Fig. 14. Here the machine is used for welding a bracket to a cream separator pail shell. The operator first places the rivet in the bracket and shell, then places them on the electrode of the machine, as shown, turns on the current, and applies pressure. As soon as the rivet reaches a bright red heat it upsets considerably, but owing to the large size of rivets used, the electrodes are not depended upon to completely upset the rivet, as this would cause

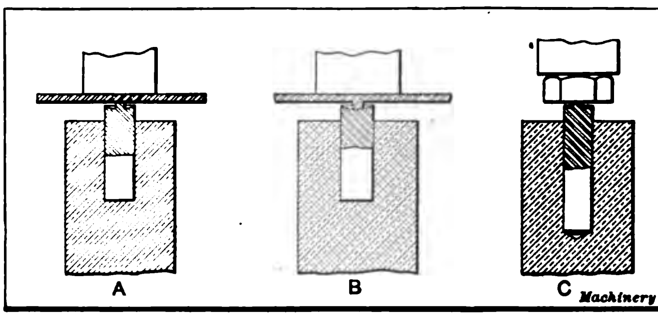


Fig. 15. Diagram illustrating Process of uniting Sheets to Studs and Bolt Bodies to Heads

excessive wear of the electrodes. The work is, therefore, removed from the machine as soon as the rivet is thoroughly heated and smashed down with a hammer on the block shown. One operator can turn out 900 riveted shells in nine hours by this method.

Butt-welding on Spot-welding Machine. — One process performed on the spot-welding machine which resembles butt-welding is shown in Fig. 15. At *A* is shown one method of welding a rod to a sheet. In order to localize the current at one point, the rod is prepared with a teat and a cup-shaped top. The teat first comes in contact with the sheet, and as the teat is broken down by the pressure of the electrode, the ring around the edge of the rod comes in contact with the sheet, making a second connection, and greatly intensifies the resistance to the flow of the current,

so that the rod can be welded to the sheet without leaving any burr. Another modification of this principle is shown at *B*. In this case the sheet instead of the rod is prepared with a teat, and the rod is made with a concave or cupped end; *C* in the same illustration shows still another method which is applied in this case to a hexagon bolt. This application is identical with that shown at *A*, except that a bolt-head instead of a thin sheet of metal is being welded. This method of making cap-screws economizes in material.

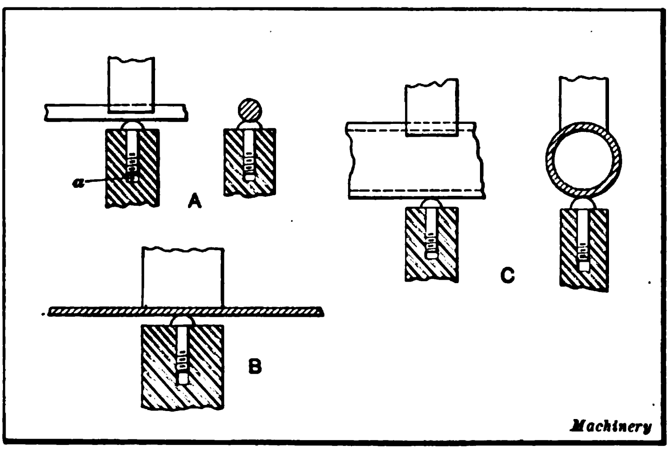


Fig. 16. Diagram illustrating Processes of welding Screws to Sheet Tubing, etc.

Fig. 16 shows some additional examples of butt-welding done on a spot-welding machine. At *A* is shown a method of welding a screw to a rod. This can be done very satisfactorily on the spot-welding machine, provided that a clearance is left at the bottom of the screw or at the point *a* so that the electrode makes contact only with the rim or head of the screw. This enables the welding to be done rapidly and decreases the amount of current used. A somewhat similar method of welding is shown at *B*. Here a screw is welded to a sheet. The process in this case is identical with that shown at *A*, with the exception of a slight change in the shape of the upper electrode.

Another modification of this principle is shown at *C*. In this case the screw is welded to a tube. There are two points in connection with this method that should be closely observed: First, the screw must be located in relation to the tube so that the axis of the screw is in line with the axis of the tube and the upper electrode. If this is not the case, there will be a slight deflective movement, and a satisfactory weld cannot be made; second, the

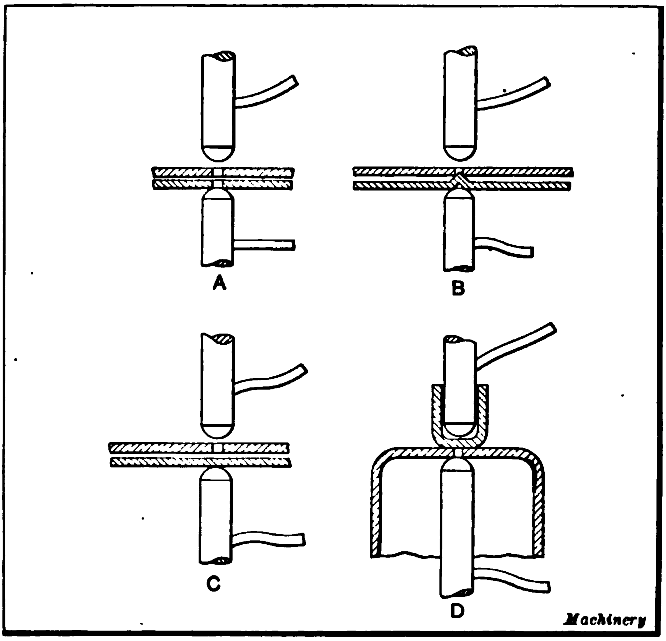


Fig. 17. Diagram illustrating Processes used in Spot-welding Large Articles

welding must be done very rapidly; the quicker the welding is done, the better the results obtained.

Spot-welding Large Articles. — When it is desired to electrically weld large articles at a point, several different processes, as shown in Fig. 17, can be adopted. One process, shown at *A*, consists in drilling two small holes through the pieces of metal to be welded. When the electric current is applied and the electrodes are brought in contact with the two sheets, the current is

localized around the hole and does not spread into the material, as is the case when the electrodes are simply brought down in contact with the surface of the material. It, therefore, requires less power and shorter time to make the weld. A modification of this method is shown at *B*. Here one piece has a hole drilled in it and the other is provided with a projection. This still further decreases the amount of power required to make the weld. The method shown at *C* is similar to that at *A* with the exception

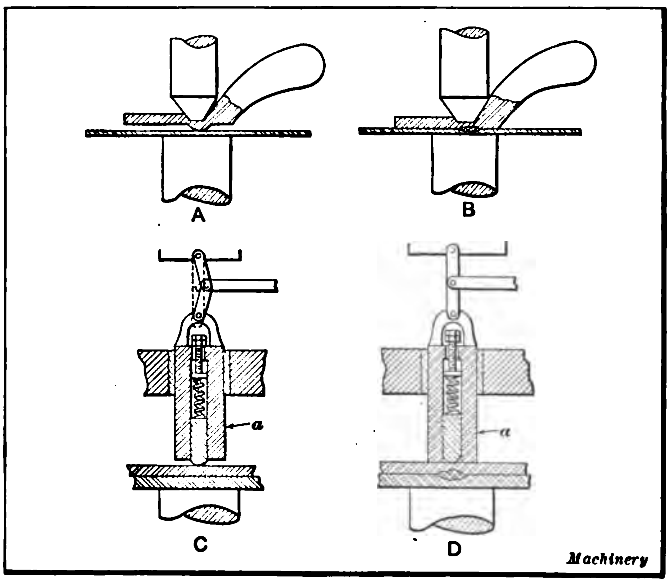


Fig. 18. Diagram illustrating Principles of welding Thick to Thin Metal and welding Thick Sheets of Metal

that only one piece is provided with a hole. The method shown at *D* illustrates the method of welding a small cup to a larger one. In this case, the large cup is provided with a hole for localizing the current.

Welding Thick to Thin Metal. — Little difficulty is experienced in welding two pieces of sheet steel of the same thickness, but when the thicknesses of the two parts to be welded are unequal, difficulty is sometimes encountered in obtaining a perfect junction. The reason for this is that the thin sheet heats up more

quickly than the thicker one and is burned before the thick sheet reaches a welding temperature. One method of satisfactorily welding a thick sheet to a thin one is shown at *A* and *B* in Fig. 18. In order to prepare the thicker piece to be welded, a point or pro-

Fig. 19. Special Electric Spot-welder having a Capacity to weld Two Plates each 1¼-inch Thick and applying Hydraulic Pressure for Operating the Upper Electrode

jection is formed on the lower surface of the thick piece. This localizes the current, and both pieces — thick and thin — heat up at the same time, so that, when pressure is applied, a perfect junction can be made.

Welding Thick Work. — As has been previously stated, the limit of spot-welding practice is reached when the pressure necessary to bring the sheets of metal into intimate contact is such that upsetting of the copper electrodes takes place. At *C* and *D* in Fig. 18 is shown a method of applying mechanical means for securing a contact between the two sheets to be welded. The hardened steel sleeve *a* is connected by a toggle mechanism to a hydraulic or air cylinder. To effect the weld, the pressure is then

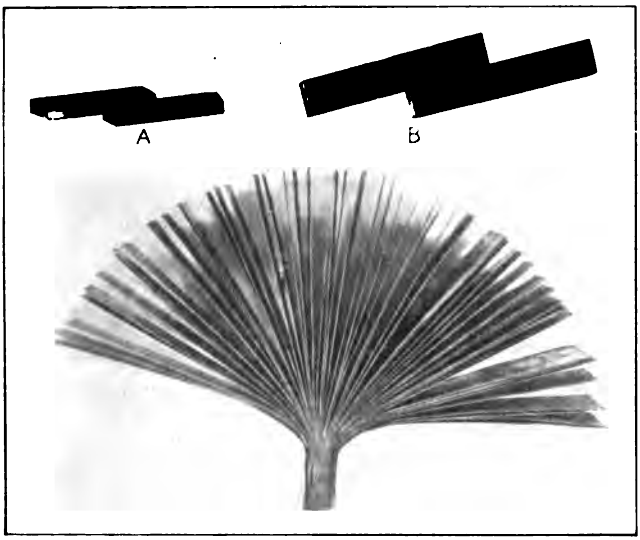


Fig. 20. Examples showing Possibilities of welding Thick Materials

applied and the hardened steel sleeve is brought down into contact with the surface of the sheets, pressing them against a lower electrode, which, preferably, should be made from a large block of copper. When the sheets have been brought down into intimate contact, the current is turned on, and as the electrode is held in contact with the sheet by means of a very stiff spring, the pressure exerted by the electrode is sufficient to fuse the sheets together when they reach the proper temperature. A practical application of this principle, in which the steel dies are dispensed with, is shown in Fig. 19. In this case, large copper electrodes —

the upper one 2½ and the lower one 3 inches in diameter — are used to both heat and press the metal together. This machine, which has a capacity for welding two strips 1¼-inch thick, exerts a pressure of 50 tons, and is operated hydraulically. The slide carrying the upper electrode is operated through a toggle-joint,

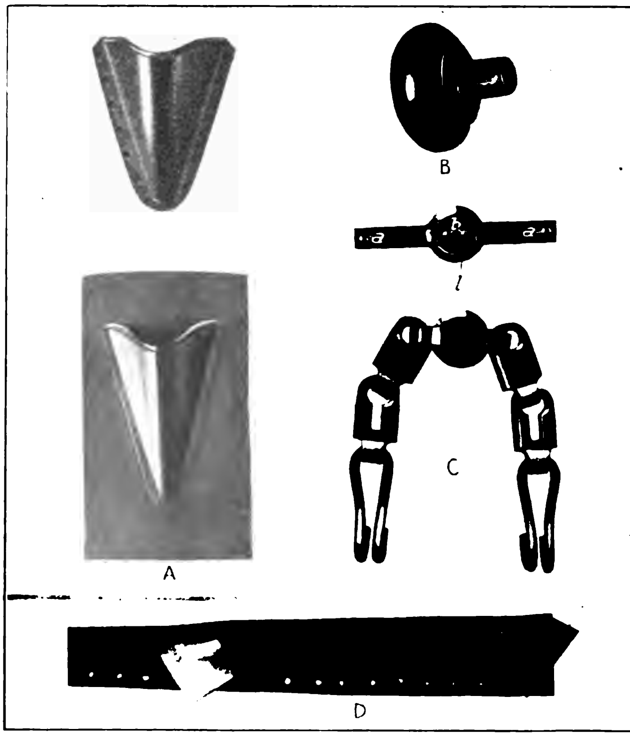


Fig. 21. Illustration of the Application of the Point Method of Electric Welding

receiving pressure from a hydraulic ram. The maximum capacity is 100 kilowatts.

The generally accepted idea that spot-welding is practical to only as high as ⅛-inch thickness of sheet is fully disproved in recent practice. By the use of simple methods, there is practically no limit to the thickness which can be spot-welded. This is indicated in Fig. 20, where two bars, each ⅞-inch thick, have

been spot-welded together. The operation took about one minute.

Point- or Projection-welding. — As mentioned, the welding of sheet metal is not restricted to one spot at a time, as any reasonable number of welds can be made at one operation by the method known as "point-" or "projection-welding." In such welding, used, for example, for cooking utensils, sash pulleys, etc., the parts when stamped have small projections raised above the plane surface of the metal, the height of the projection varying

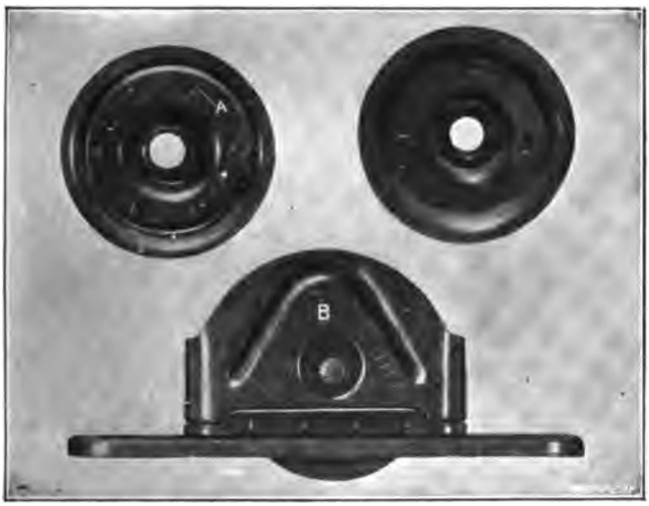


Fig. 22. Sash Pulley and Housing welded by the Point Method

according to the gage of the material. When welding such parts, properly shaped copper electrodes are fitted to them. Each point acts as a resistance to the passage of the welding current. The current divides itself among these points and by their resistance to its passage, each becomes a heated welding point. Pressure applied to the softening metal completes all the welds simultaneously. Fig. 21 shows a spout welded to a coffee pot at twenty-three distinct points.

A marked distinction exists between the two methods of spot- and point-welding, as many cases occur when the spot method cannot be used, but the point method proves perfectly successful

and commercial. Fig. 21 illustrates an "anti-skid" chain which is an excellent example. In making this chain the spot-welding method was first tried by the manufacturer. The point method was then applied, raising points on both the body and the strap, and resulting in a perfect weld. The output by the spot method was 600 per day of unsatisfactory welds; by the point method, 3000 good welds. Another excellent example is that of the door knob shown in Fig. 21. The shank is welded to the hollow knob

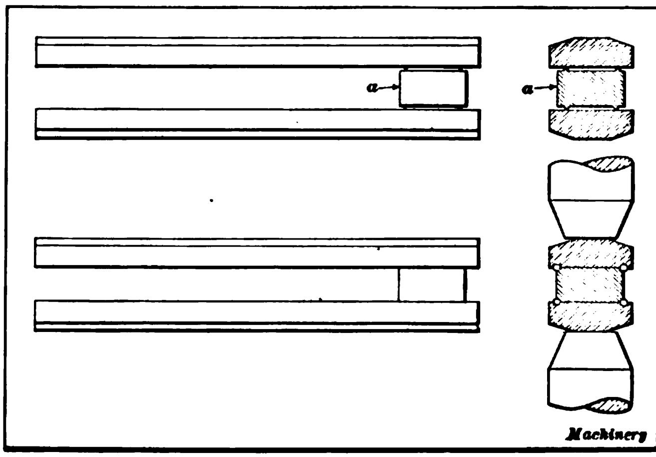


Fig. 23. Diagram illustrating Principle applied in the Spot-welding of Telephone Transmitter Magnet Bars without drawing the Temper

at six distinct points. It is impossible to weld this except by the point method.

Fig. 22 shows a sash pulley and housing which is an example of point-welding. The pulley is made in halves, one-half having an annular ridge and the other, six projections or raised points *A*. When the points of one-half are brought into contact with the ridge on the other, the electric current, being concentrated, fuses the metal instantly, and six homogeneous point- or spot-welds are produced. These pulleys are welded on the automatic machine shown in Fig. 36, which will be described in detail later. The housing *B* is also made in two parts, each of which is joined to the baseplate by four point-welds as shown. The anti-skid

chain for automobiles, shown at *C*, Fig. 21, previously mentioned, has the central link *l* welded as indicated. The link is drop-forged with raised points at *a* and *b* which form the welds after the wings are bent over onto the central part. The strength of the point-weld is indicated by the sample shown at *D*. An attempt to tear the small pieces from the steel strip resulted in shearing the metal around the weld, but in no case did the weld prove defective.

There are numerous applications of point- or projection-welding which can be accomplished on an electric spot-welding machine. The example shown at *A* in Fig. 18 illustrates one of the simplest processes employed. Fig. 23 shows a process which is not as well known, and which has remarkable possibilities. By the ordinary method of performing electric spot-welding operations, it is impossible to join two hardened pieces without drawing the temper. There are cases, however, where it is desirable to secure a good weld without drawing the temper, the magnet bars used in a telephone receiver being an example in point. Those familiar with this work know that magnet bars in telephone transmitters should be as permanent as possible, and for this reason a special material known as magnet steel is used; this is hardened to a glass hardness. Formerly, difficulty was encountered in joining the two bars of the magnet, because of the extreme hardness of the pieces. The method generally employed was to drill holes through each end of the magnet and through the spacing keeper and then rivet the members together. This method had the serious objection that in riveting the pieces it was difficult to avoid breaking the magnets, owing to their extreme hardness and consequent brittleness, so that a considerable percentage of magnets were spoiled during the final riveting operation.

Electric welding has greatly simplified this problem by uniting the three pieces rigidly without drawing the temper of the magnets. The manner in which this is done is interesting. The spacing bar shown at *a* in Fig. 23 is provided with knife-shaped circular ridges about $\frac{1}{64}$ inch high. The pieces are then assembled in a fixture to hold them in the proper position and placed between the electrodes of a spot-welding machine es-

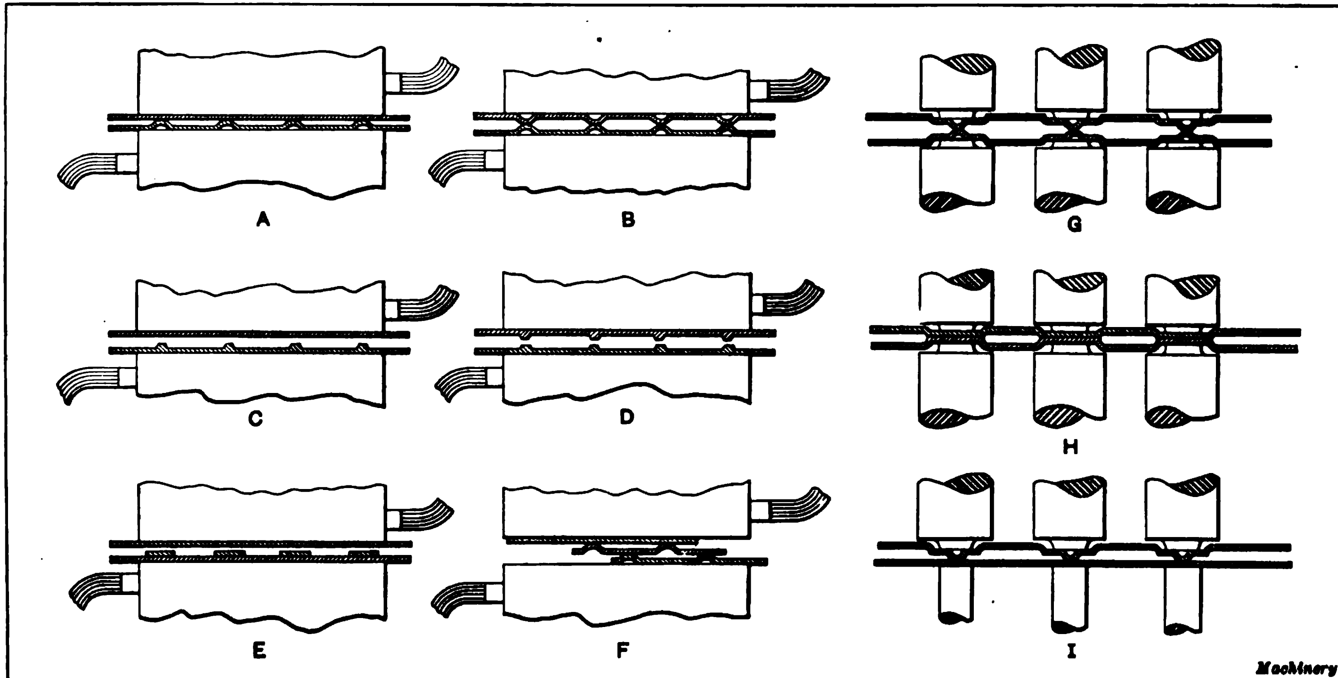


Fig. 24. Diagram Illustrating Various Processes of accomplishing Multiple Point- or Projection-welding and Multiple Electrode Welding

pecially fitted to provide an amperage of about 2000 amperes. The electrodes are then brought in contact with the work, the current turned on, and the weld made in a fraction of a second. So rapidly is the weld made that the metal is not annealed; it does not have time to heat except at the knife-edge point where the weld is actually made. Practically no flash is formed and the pieces are rigidly united.

Multiple Point- or Projection-welding. — In electric welding of comparatively large pieces of thin metal, where it is desirable to have the pieces lie in close proximity to each other, the multiple point or projection method of welding can be employed with success. Some of the processes employed for this purpose are illustrated in Fig. 24: *A* shows a case where one sheet only is provided with projections; *B*, where two sheets are provided with projections; *C*, where projections are formed in the sheet by milling; *D*, where projections are formed in both sheets in a similar manner; *E*, where the button method is employed; and *F*, where three sheets are being united. The disadvantages of the button method are that it is difficult to locate the buttons in the correct position to each other, and it is much slower than the other processes. On the other hand, it requires no special preparation of the material previous to welding.

A modification of the principle illustrated at the left-hand side of Fig. 24 is shown on the right-hand side of the same illustration. In this case, instead of using long, flat electrodes, series of electrodes are employed. This process applies particularly to the manufacture of sheet steel radiators; *G* shows how the metal is prepared with points for welding and *H* shows the result of the weld; *I* is a modification of the process in which only one sheet is provided with projections.

Multiple Electrode Welding. — In Fig. 25 is an application of what might be called multiple point- or projection-welding. In this case, it is desirable to weld a number of pins to a sheet, and as these pins generally vary in length, provision must be made for taking care of this discrepancy so that all pins will make contact at the same time. The diagram illustrates the principle of the machine designed for this purpose. The pins are lo-

cated in a plate *A* which acts as a cooling agent for conducting away the heat, and is supported and insulated, as shown. The pins rest in small cup-shaped grooves in the lower electrodes which are spring mounted so as to take care of any variation in the thickness of the metal and the length of the pins. The two

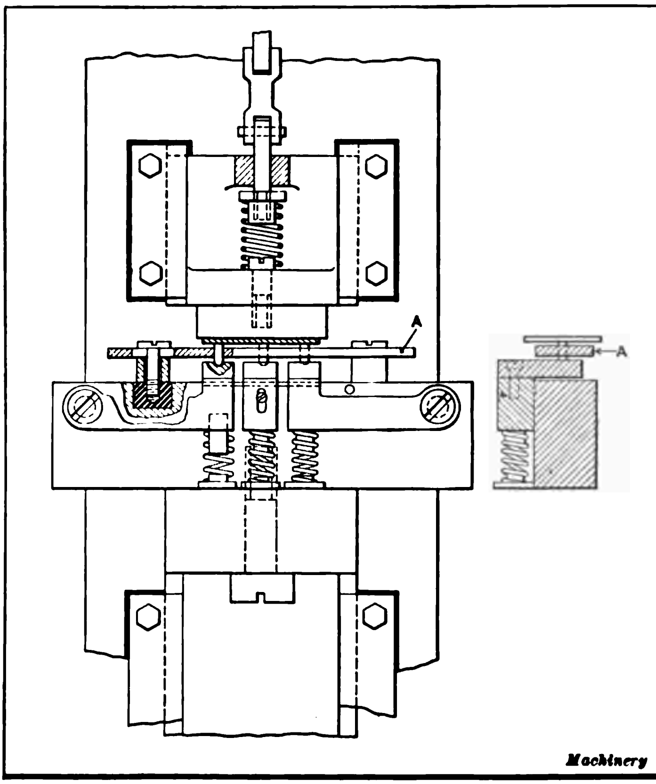


Fig. 25. Diagram illustrating Principle of Machine employing Three Electrodes for Welding Pins to Sheet Steel — Compensation is made for Variation in Length of Pins

side-electrodes are swung from a fulcrum point, whereas the center-electrode, as shown in the sectional view to the right, is in the form of a slide.

The diagram shown in Fig. 26 illustrates several methods of supplying current from the same transformer secondary to

several pieces engaging electrodes in such a manner that the same heating effect is produced in all the pieces with which the electrodes make contact. In the case shown at *A*, the secondary of the transformer is composed of a heavy copper casting *a*; *b* is the primary, and *c* the laminated iron core. The terminals *d* and *e* of the secondary extend in opposite directions, so that the difference of potential across any pair of electrodes is the

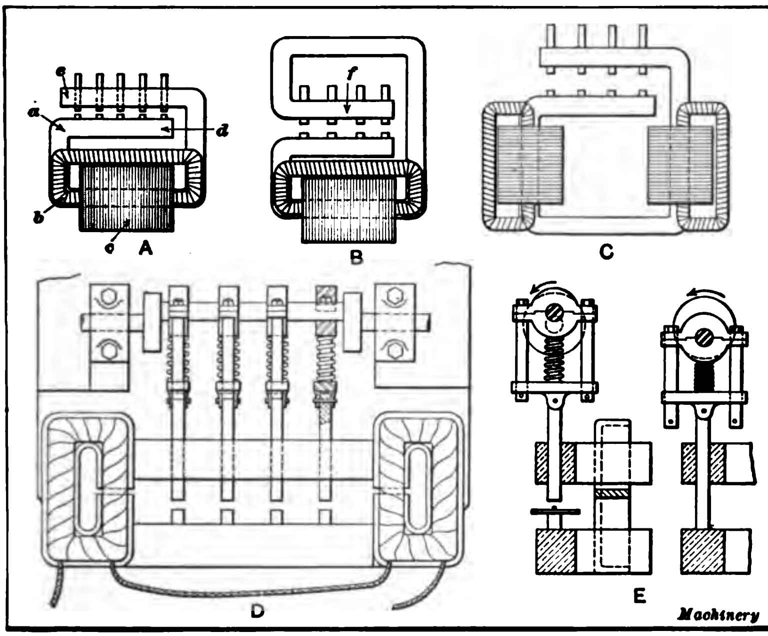


Fig. 26. Diagram illustrating Principle of Design of Multiple Electrode Welding Machines

same. This will be made more clear by referring to the diagram shown at *B*. Here the terminal bars *f* extend in the same direction, and the difference of potential across each pair of electrodes varies for each pair.

The diagram shown at *C* illustrates the application of two primaries or sets of primary coils which act upon the same secondary bar or casting in such a manner as to give an increased potential across the bars due to the fact that the electro-

motive forces set up in the secondary by the primary act in series to reinforce one another. In this case, two laminated cores can also be used to advantage. By arranging the current carrying the secondary bars in this manner, an equal potential force is obtained so that a satisfactory weld can be made by each of the individual electrodes. At *D* and *E* is shown a diagram of an automatic welding machine incorporating the multi-electrode principle shown at *C*.

Ridge-welding. — To facilitate the assembling of parts, a further improvement was made by the introduction of so-

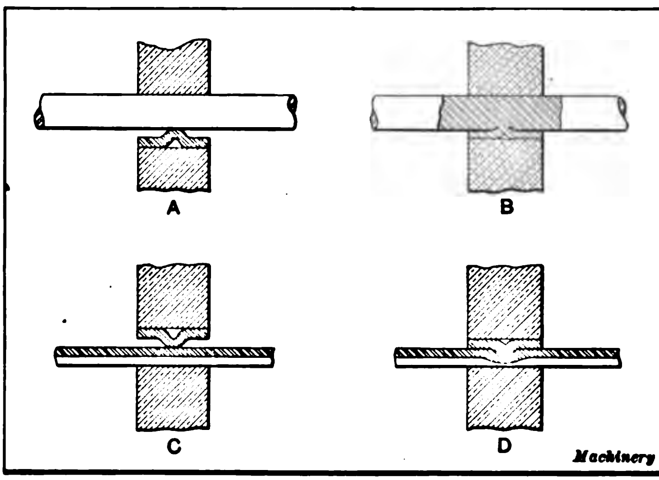


Fig. 27. Diagram illustrating Process known as "Ridge-welding"

called "ridge-welding." The result of two ridges crossing is the same as of two points, and the operation of making the weld is identically the same. Both point- and ridge-welding permit the use of large flat blocks of copper for electrodes, the heat being localized by the points or ridges forming the welding spot. In both these methods, the electrodes require very little attention, except an occasional touch with a file over the surface, as against continual shaping of small pointed electrodes. The ridges are generally placed at right angles to each other, forming a cross at the point where the weld is made. Two examples

of this class of work are shown in Fig. 27. Example *A* shows a rod being welded to a narrow strip provided with a ridge in the center. In this case the circumference or arc on the rod acts in the same manner as a ridge, and by turning on the current and applying pressure these two pieces can be homogeneously united, as shown at *B*. Another method which makes use of two strips, both of which are provided with ridges, is shown at *C*. The action of welding these two pieces together is similar to that previously described, the finished weld being shown at *D*.

Fig. 28 shows an example of ridge-welding. This is part of a go-cart frame. The stock from which the end pieces are made

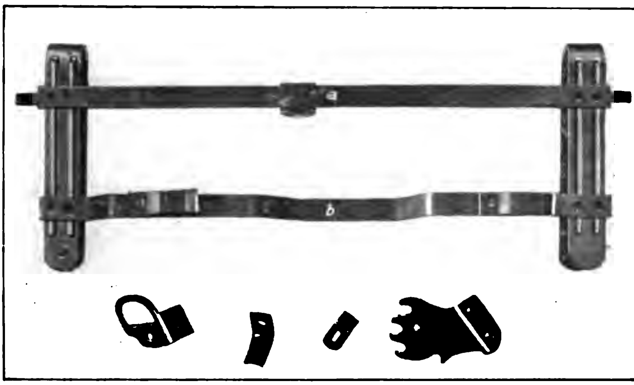


Fig. 28. Examples of Ridge-welding

has ridges rolled in it as shown. The cross-bar *a* is provided with two raised points at each end that come directly over the ridges, and the bar *b* has concave ends, thus giving contact points where the curved edges rest on the ridges. Beneath this frame a number of small parts are shown that are prepared with projections ready for welding. The ridge method of welding is also used for welding reinforced concrete frames, the ridges which form the points of contact being originally rolled in the stock. Generally speaking, the ridge method is preferable to the point method, owing to the greater facility in assembling parts prior to welding; the ridges also stiffen and strengthen the material. The

results obtained by the ridge method are, as far as the quality of the weld is concerned, practically the same as when projections or points are used.

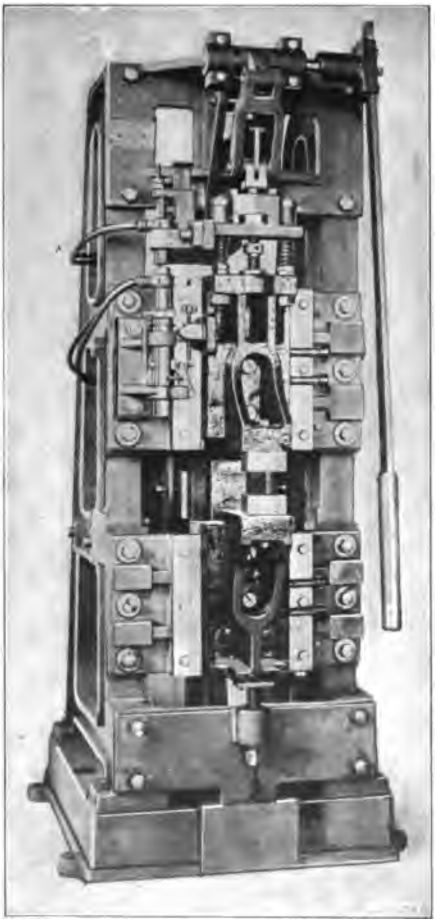


Fig. 29. Type of Electric Welding Machine for Heavy Work

Types of Welding Machines. — The machine used for point- and ridge-welding is equipped with large copper electrodes instead of the pointed type, and the current is concentrated at the points to be welded by the small raised projections, as mentioned, instead of by reducing the area of the electrodes. With the large electrodes, sufficient current for welding heavy stock can be conducted without excessive heating and deterioration. A Universal Electric Welding Co.'s welding machine having these large electrodes is illustrated in Fig. 29, which shows a standard type intended for general work. This machine may be either hand-operated, as shown, or may be made semi-automatic, belt-driven. When a great quantity of similar articles is to be made, special machines are usually built.

Button-welding. — Another welding process which has been used with satisfactory results is that known as "button-welding." In addition to many other uses, this can be applied to the weld-

ing of very thick work which it would be impossible to spot-weld because of the fact that the metal could not be brought into close contact without applying enormous pressure. By this method, a button of metal of the same material as that being welded is held on the top or bottom electrode or on both, as the case may

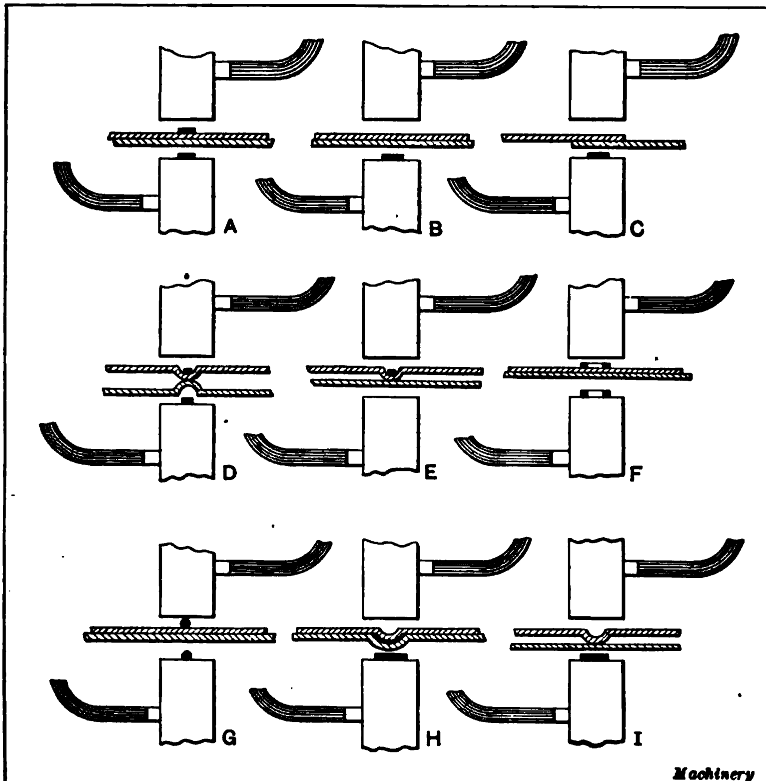


Fig. 30. Diagram illustrating Various Processes employed in welding Two Sheets of Steel by means of Buttons

be; then the two pieces to be welded are placed between these buttons and pressure is applied on top of the button. The current is then turned on and the buttons localize the current, resulting in the metal being fused at the point where the buttons are located; when pressure is applied, the partially molten buttons are forced through the already molten metal and a

perfect junction is made. Several applications of this process are shown in Fig. 30: *A* shows one method where two buttons are used; *B*, one button; *C*, a case where one button is used to perform a lap-weld; *D*, a combination of button- and point-welding (this is a special process and is seldom used); *E*, a case

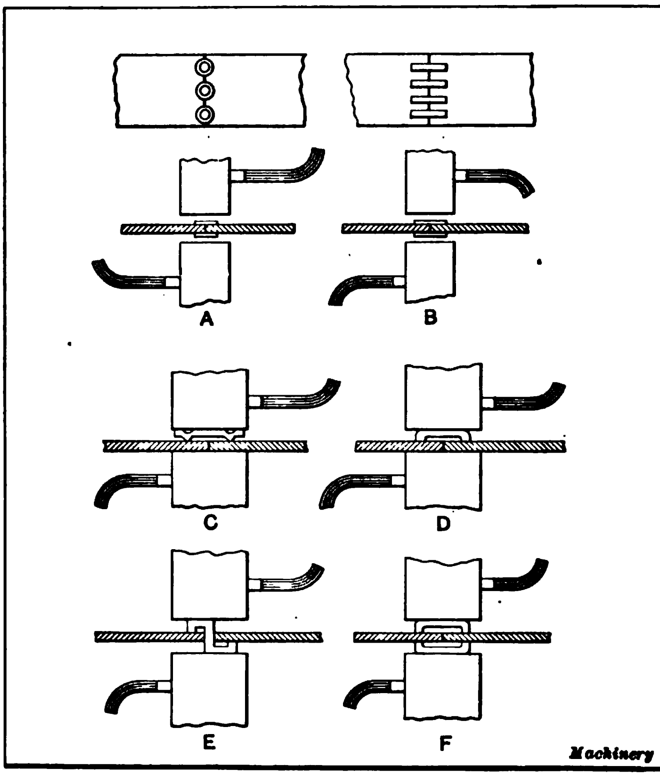


Fig. 31. Diagram illustrating Principle employed in accomplishing Process known as "Bridge-" or "Tie-welding," permitting the joining of Narrow Strips without decreasing Length

where a point and one button are used; and *F*, buttons in the form of rings. The example shown at *G* is one in which pieces of wire are employed in the place of flat buttons; *H* is a case where the two pieces are provided with projections fitting in each other and a button used in addition; *I* represents a somewhat similar

case to that shown at H. All of these processes have not been used in practice, but represent possibilities of electric welding.

Bridge- or Tie-welding. — When it is desired to unite two narrow strips so that their ends abut without overlapping, this can be done by the process known as "bridge-" or "tie-welding." Several applications of this process are illustrated in Fig. 31. One process illustrated at A consists in using a number of small flat washers, all of which lie in the same plane and are superimposed on the plates to be welded, making contact therewith. When the current is turned on and pressure applied, these pieces are fused, and make a junction point between the two strips of metal, leaving practically little or no burr; B shows a slight modification of this process, using solid strips instead of washers; C is a combination of bridge- and point-welding, the bridge being provided with projections which localize the current and effect quick heating. This process does not give as solid a junction as those previously described. A similar process is shown at D to which there is the same objection; E is still another process which, while it effects a junction between the two pieces, does not give a strong joint; F is a somewhat similar process to D, employing two bridges instead of one, to which there is the same objection as to the processes illustrated at C and D.

Tee-welding. — A process of electric welding which has a wide application in the agricultural field is known as "tee-welding." This process is used to special advantage in the manufacture of garden rakes and, as shown in Fig. 32, has many modifications. At A is shown one method of effecting a weld. The top part of the rake is provided with a slot running its entire length, and the tangs which are welded to it are provided with projections fitting in this slot. These tangs are then satisfactorily welded to the frame under a spot-welding machine. Another method is shown at B. In this case the current is localized by providing points by milling away the sides of the top of the rake; C shows still another method; here the outside of the rake is provided with projections of an area equal to the lower end of the tang, so as to equalize the heating effect of the current on the parts welded.

The method shown at *D* is somewhat similar, with the exception that the projection is formed by milling two small slots across the face of the top part of the rake. A method which is the reverse of that illustrated at *D* is shown at *E*. Here both pieces are provided with projections, forming a matched joint. At *F* and *G* are shown still other methods which are limited in

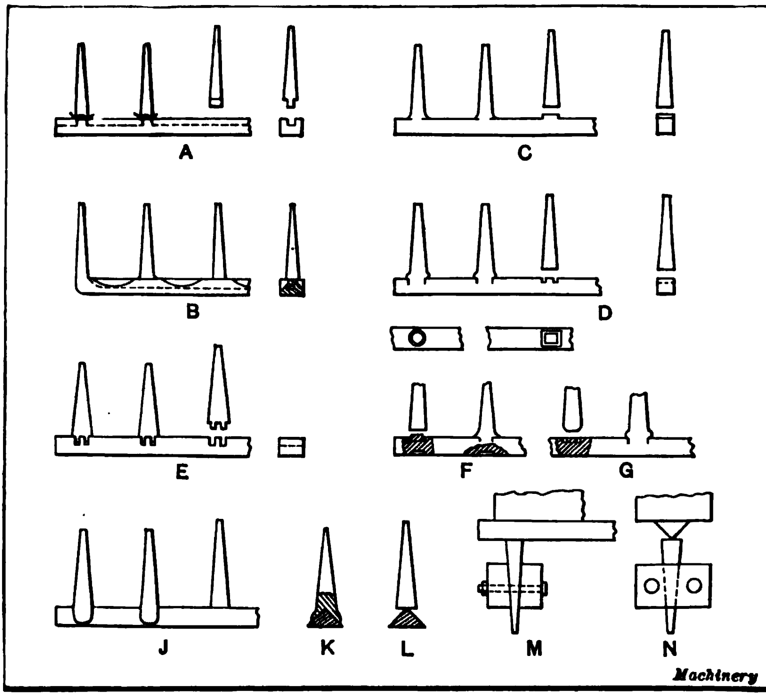


Fig. 32. Diagram illustrating Principles used in employing Process known as "Tee-welding" with Special Application to the Manufacture of Garden Rakes

their application because of the difficulty of making the required projections. The methods shown at *J*, *K*, and *L* illustrate the preparation of the work for welding and the finished welded work, *L* showing how the weld is started and *J* and *K* the form of the weld; *M* and *N* show two views illustrating how the electrodes are applied to the work to perform a weld as shown at *J*, *K*, and *L*, respectively.

A practical application of this process of welding is shown in Fig. 33. In this case, the tangs of the rake are made from $\frac{1}{4}$-inch round steel rods, which are welded to a triangular back $\frac{1}{4}$ by $\frac{7}{16}$ inch. There are fourteen teeth in each rake and one

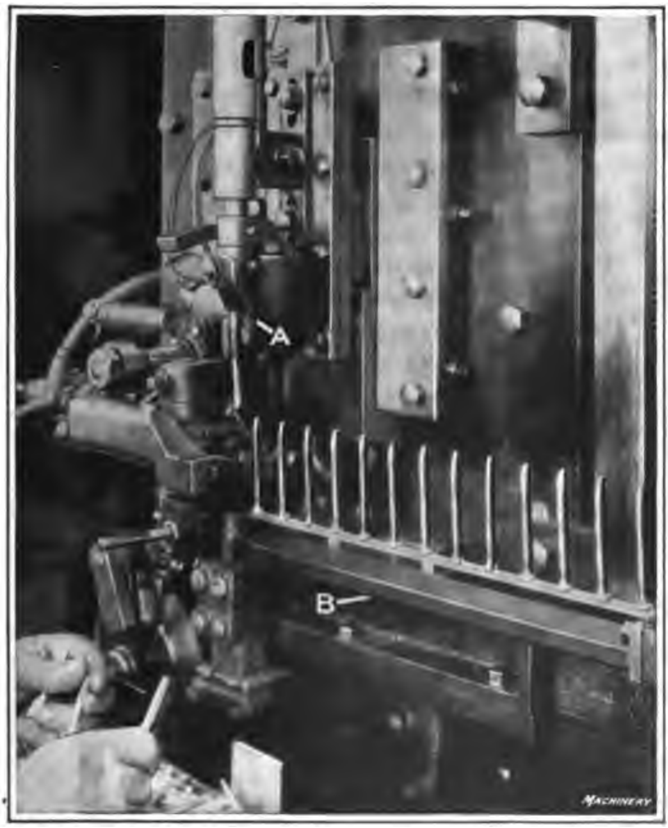


Fig. 33. Semi-automatic Machine built by the National Electric Welder Co. for Welding Garden Rakes

operator produces 375 rakes in nine hours, or, in other words, he makes 5250 welds in this time. In operating this machine, the tangs are placed in the solenoid *A* and the back is placed on slide *B*; the machine then automatically spaces, sets, and welds the tangs to the back at the rate previously mentioned.

Sheave Welding. — A class of work in which the point or projection method of electric welding is used to good advantage is the manufacture of sheaves for window sashes. Two methods of applying this process are illustrated, diagrammatically, at *A* and *B* in Fig. 34. In the example shown at *A*, the two halves of the sheaves are prepared with ridge projections which fit into each other; in the case shown at *B*, one-half is provided with

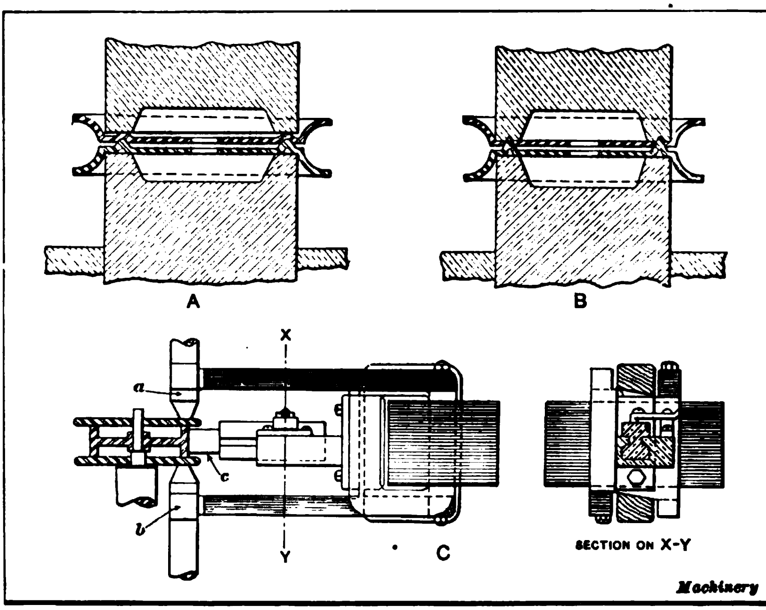


Fig. 34. Diagram illustrating Various Processes employed in the Manufacture of Sheaves or Pulleys

point projections and the other with holes to receive them. Usually this work is done in a semi-automatic manner, and a special machine has been designed for this work as illustrated in Figs. 35 and 36. Referring to Fig. 35, the machine is provided with two drums *A* on which an endless chain *B* is carried. These drums are rotated by suitable mechanism, being indexed around to bring the pair of sheaves to be welded in line with the welding electrodes. The sheaves remain in line with the welding electrodes for a sufficient length of time for the weld to be effected.

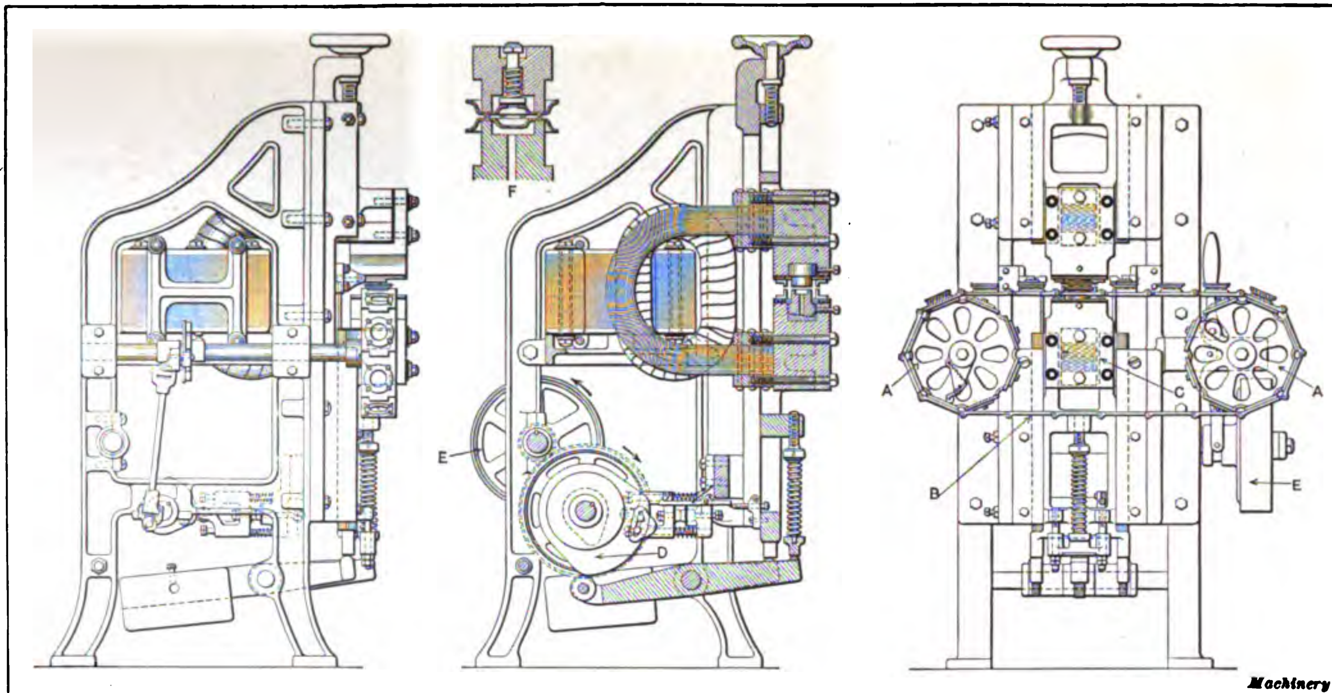


Fig. 35. Diagram illustrating Principle of Construction of a Semi-automatic Machine for Electric Welding Sheaves for Window Frames

The various timing mechanisms on the machine as well as the movement of the lower electrode slide *C* is controlled by cam

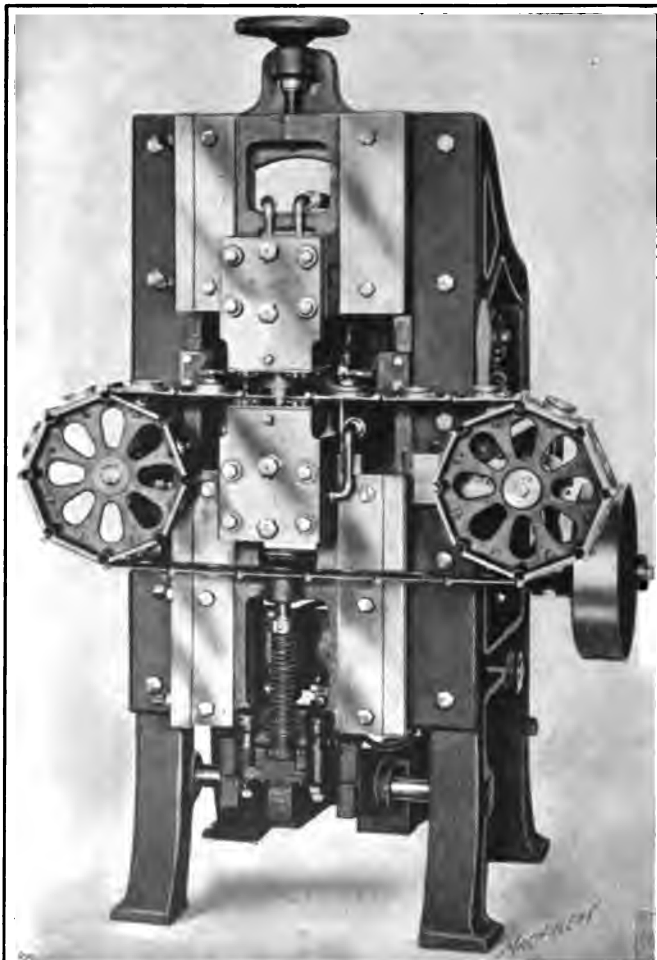


Fig. 36. Special Electric Sheave Welding Machine built by the Universal Electric Welder Co.

D, driven by gears from a main driving pulley *E*. A different electrode mechanism from that shown attached to the machine is shown in the same illustration at *F*. In this case, the upper

electrode is provided with a spring-operated pad having a non-conductive surface. This is used to prevent the work from bulging in the center when the pressure is applied to make a weld. The production of the machine shown in Figs. 35 and 36 is 15,000 sheaves in ten hours.

The diagram shown at *C* in Fig. 34 illustrates a method of welding sheaves or small pulleys employing three contacting electrodes. A single transformer is used, which permits of making more than one weld simultaneously and in which there is an even distribution of current to each weld. The secondary consists of three terminals, *a*, *b*, and *c*, one of which, *c*, is common to the other two and placed equidistantly between them, so that there will be at all times an equal distribution of the electric current through the secondary to the welding terminals. A third terminal may be connected to the turns at the connection between them, so that there is a turn between the terminals at both ends of the secondary. By using an apparatus of this kind, it is possible to confine the heating to the contacting surfaces of the work. The upper edges of the interposed electrodes conduct the current to the junction of the plate and the center of the sheave in such a manner that the core or center is not heated except on its contacting surfaces with the plate. In this way, a satisfactory weld can be easily made.

CHAPTER IV

SEAM-WELDING AND RIVETING

The seam-welding of sheets and tubes is a process which is used quite extensively in the sheet metal industry, particularly in the manufacture of utensils which must be made with steam- or water-tight joints. There are two methods in use for making a joint by this process — one is to lap the joint and the other is to butt it. Tubing is usually butt-welded, whereas sheets are generally lap-welded. Seam-welding is extensively employed in the manufacture of tubing which is used in place of cold-drawn seamless tubing, as it is not so costly to manufacture. In making a seam- or lap-weld, it is absolutely necessary that clean pickled stock be used in order to obtain the best results. When a copper roller is used, a slight amount of scale adhering to the roller will produce a puncture when it comes in contact with the piece to be welded.

The art of seam-welding has not as yet reached the same stage of development as that of butt- or spot-welding, and hence very little practical data on this subject are available. The process can be commercially employed on sheet steel of No. 22 gage (0.0313 inch) and thinner. The stock is lapped for a distance equal to its thickness, and when the copper rollers pass over the lap, the metal is mashed down to the original thickness of the sheet. In order to avoid buckling and distortion, the material being welded should be clamped along the seam. It is difficult in some cases, however, to entirely prevent buckling, especially, when the sheet is over 14 inches in length or greater than No. 22 gage in thickness.

Materials such as pickled mild steel, tin plate, terneplate, and sheet brass are easily seam-welded. Zinc, aluminum, and copper, however, are more difficult, and are not electric seam-welded on a commercial basis. In the case of utensils, such as coffee pots,

pails, pans, etc., which require coating with enamel, this process is of considerable advantage. After the enamel is applied and the article baked, it is impossible to detect the seam.

Lap-welding on a Spot-welding Machine. — For joining steel sheets which do not require a water- or steam-tight joint, a

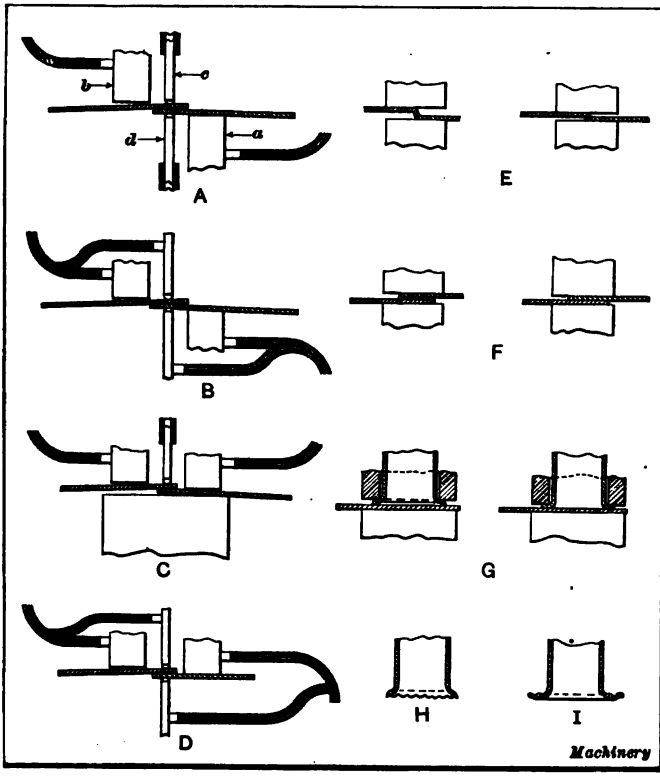


Fig. 1. Diagram illustrating Various Methods of accomplishing Lap-welding Operations on Spot-welding Machine

spot-welding machine can be employed by making certain modifications, depending upon the character of the work and the class of weld desired. Several methods of doing this work are illustrated in Fig. 1. When making a lap-welded joint by means of spot-welding in the ordinary manner, the welded spot generally covers so much surface as to distort the metal. In

Fig. 1, *A* shows a method of avoiding this. Here two sheets are shown overlapping each other and resting on poles *a* and *b* which are connected to an electric circuit. Above and below the lapped joint are two punches *c* and *d* placed in line with each other and surrounded with some insulating material. These are brought in contact with the sheets at the point where the weld is desired, and when the current is turned on it passes through the poles *a* and *b*, and is localized at the point where the two punches come in contact with the work. Fusion takes place at this point of resistance, and, when the correct temperature is reached, the two punches are brought together, forcing the heated material together.

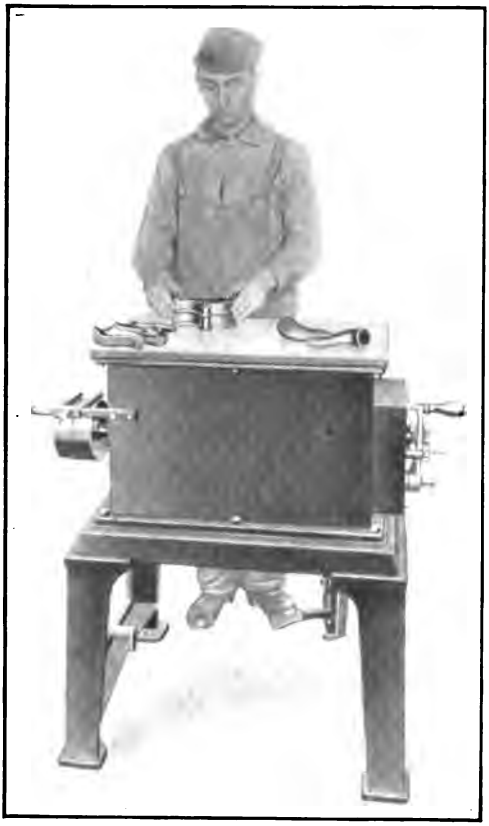


Fig. 2. Special Electric Seam-welder used principally for Welding Teapot Spouts

A slightly different application of this method is shown at *B*. Here the current, in addition to passing through the two poles, also passes through the punches. This method is particularly suitable for welding comparatively thick sheets. At *C* is shown still another modification. In this case, a large lower anvil, not connected with the electric circuit, and two poles located in the same position are used. Only one punch is used, the required pressure being

resisted by the lower anvil; the punch is not connected with the electric circuit. A modification of the methods shown at *B* and *C* appears at *D*. In this case the two poles are also connected with the electric circuit.

Several other methods of accomplishing lap-welding operations on a spot-welding machine are shown at *E*, *F*, and *G*. At *E*, both sheets to be welded are bent over at the ends so as to localize the current. After the correct temperature has been reached, pressure is applied, resulting in a weld as shown in the right-hand view of the same illustration. Still another

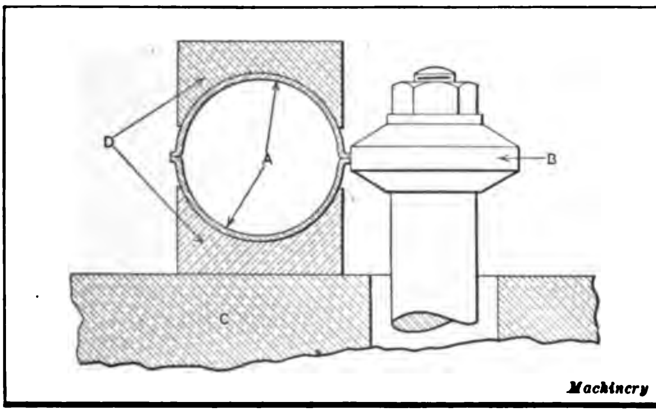


Fig. 3. Diagram showing Method of welding Teapot Spouts on Machine shown in Fig. 2

method is shown at *F*, in which only one strip has a turned-over edge. Here the welded junction takes place at a considerable distance from the edge of the strip. A method which can be used for welding a tube to a sheet is shown at *G*. In this case, the lower electrode is made flat and the upper electrode is in the form of a ring surrounding the tube as shown. The lower end of the tube is expanded, so that, when heat and pressure are applied, the lap-welded joint as shown at the right is produced. Two other methods of forming the lower end of a tube to be welded to a sheet are shown at *H* and *I*, the form shown at *H* giving what might be called a projection-weld, and that shown at *I* giving a ridge-weld.

Seam-welding Teapot Spouts. — A special seam-welding machine used principally for welding kitchen utensils and similar work is shown in Fig. 2. This is a comparatively small machine, and is adapted particularly for welding teapot spouts. The diagram shown in Fig. 3 illustrates how this machine operates. The two halves of the spout *A* are stamped to the proper shape

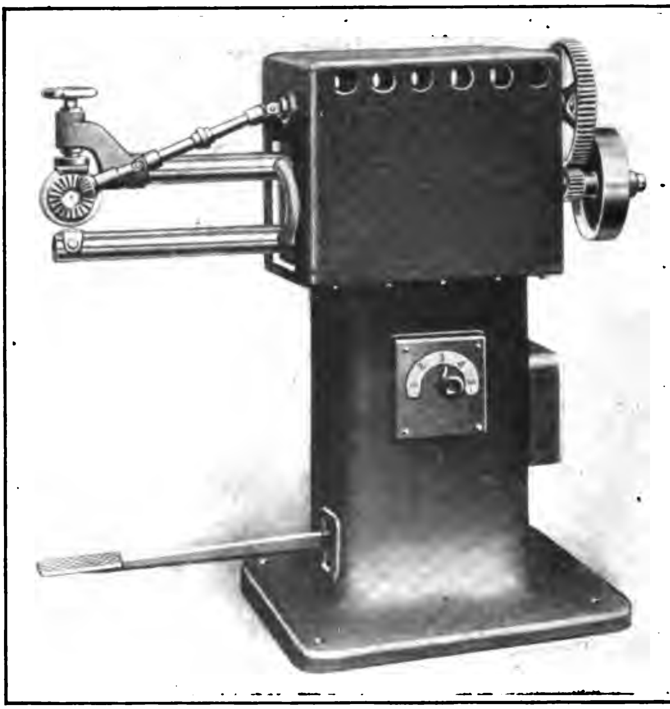


Fig. 4. Special Electric Seam-welder used for Welding Sheet Steel of Light Gage

in a press and trimmed so that a slight projection is left extending from the edges as shown. One electrode of the machine is a copper roller *B*, mounted on a shaft that carries the current, rotating at 100 revolutions per minute. The other electrode is the top of the table *C*. In operation, the two halves of the spout *A* are clamped in copper holders *D*, and as these rest on the top of the copper table, the current passes through them, forming

the second electrode. Therefore, when the edges of the spout are brought up against the copper roller *B* and passed by it, the thin metal in the edges is quickly fused and pressed down so that a smoothly finished surface is produced. The holder is then

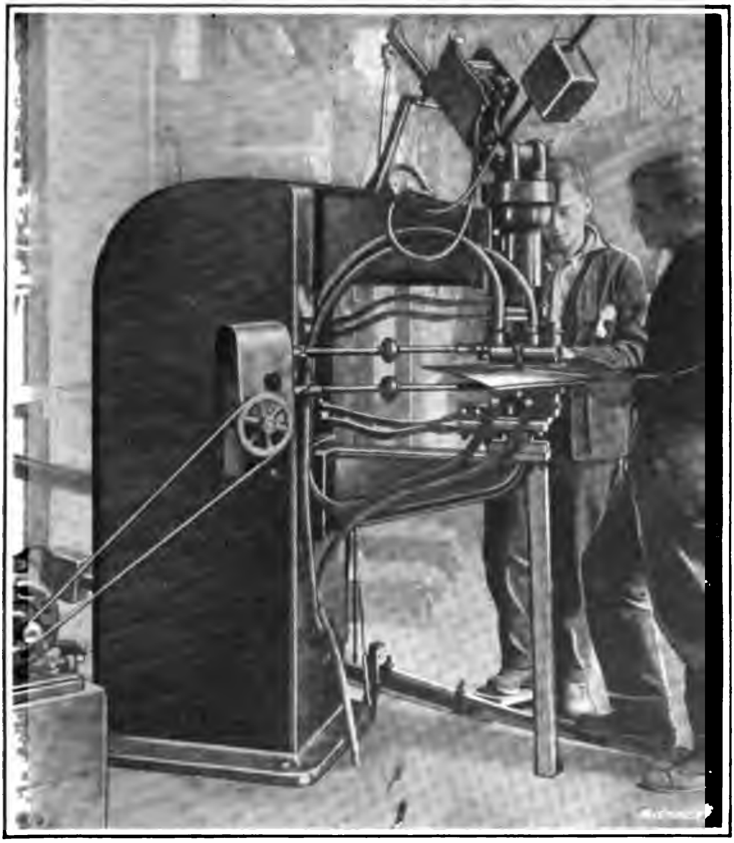


Fig. 5. Spot-welder especially fitted up for Seam-welding

turned around, presenting the other edge or side of the spout to the roller and the operation repeated. One boy can weld an average of 800 spouts in ten hours, and after the spout leaves the welding machine, it is ready for enameling. The machine shown in Fig. 2 is driven by a belt. The maximum capacity is 5 kilowatts.

Another seam-welding machine for welding sheet steel is shown in Fig. 4. This machine is also power-driven and can be used on various classes of light gage stock that is pickled and clean. The edges of the stock are made to overlap a distance equal to the thickness of the sheet, and are placed under a copper roller, which is mounted in an adjustable holder as shown. Pressure on the foot-treadle starts the machine, the current being automatically turned on and the stock carried through between the revolving rollers. As the stock emerges from the rollers, the current is automatically turned off. This

Fig. 6. Sample of Lap-welding accomplished on Machine shown in Fig. 5

machine cannot be used on galvanized iron or rusty and scaly sheet steel or iron. The upper roller is operated by power from a pulley at the rear through a flexible shaft and bevel gear and pinion at 100 revolutions per minute. The maximum thickness of stock that can be satisfactorily welded is $\frac{1}{16}$ inch.

Spot-welding Machine Adapted for Lap-welding. — In Fig. 5 is shown an electric welding machine arranged for lap-welding sheet steel. The regular spot-welding electrode holders have been removed and special holders substituted. These holders are water-cooled and carry copper rollers which are driven by flexible shafts from a two-horsepower motor. The work to be welded is placed between the copper rollers, and the foot-treadle operated; the electric current is turned on at the same time,

and as the sheets pass under the rollers they are heated and pressed together to form a weld. Fig. 6 shows a sample of lap-welding as done on this machine. The joint is level, but the sheets having been under considerable tension have buckled to a considerable extent. The reason for this is that the local heating of the edges of the sheets causes them to stretch, and, hence, buckle. In order to avoid this, it is necessary to clamp the sheets close to the weld.

Machine for Seam-welding Tubes and Sheets. — Several different types of machines have been designed for the seam-welding

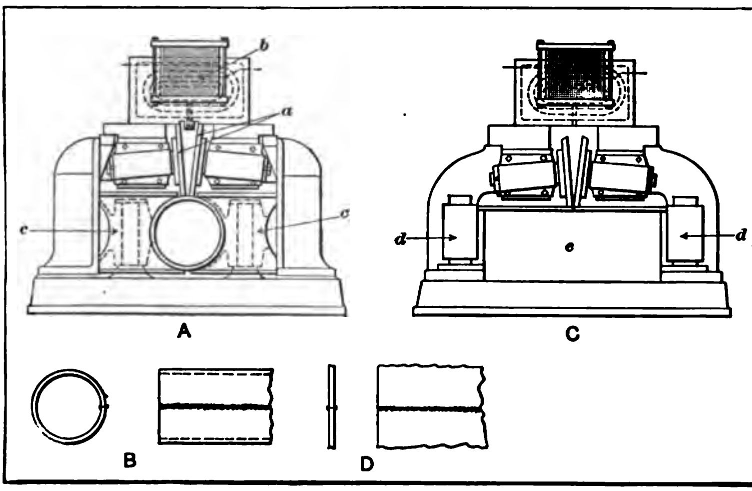


Fig. 7. Diagram illustrating Two Types of Butt-seam Welders built by the Thomson Electric Welding Co.

of tubing. One of these, shown by the diagram at *A* in Fig. 7, is of comparatively simple construction. Its chief advantage is that the working terminals are located close to the turns of the secondary, so that the work is kept outside of the space enclosed by the conductor constituting the secondary of the transformer. The working terminals of the secondary of the transformer are copper disks *a*, which are located in such a position that the working faces converge toward the side farthest from the secondary *b*. These terminals are carried on axles which, in turn, are journaled in bearings located in such a position that

disks *a* give a full bearing on the tubes to be welded. The tube is fed into the machine by rollers *c* as illustrated, being held in such a way that the seam is located equidistantly between the two copper electrode disks. The welding current passes from one pole of the secondary through one of the disks *a*, then across

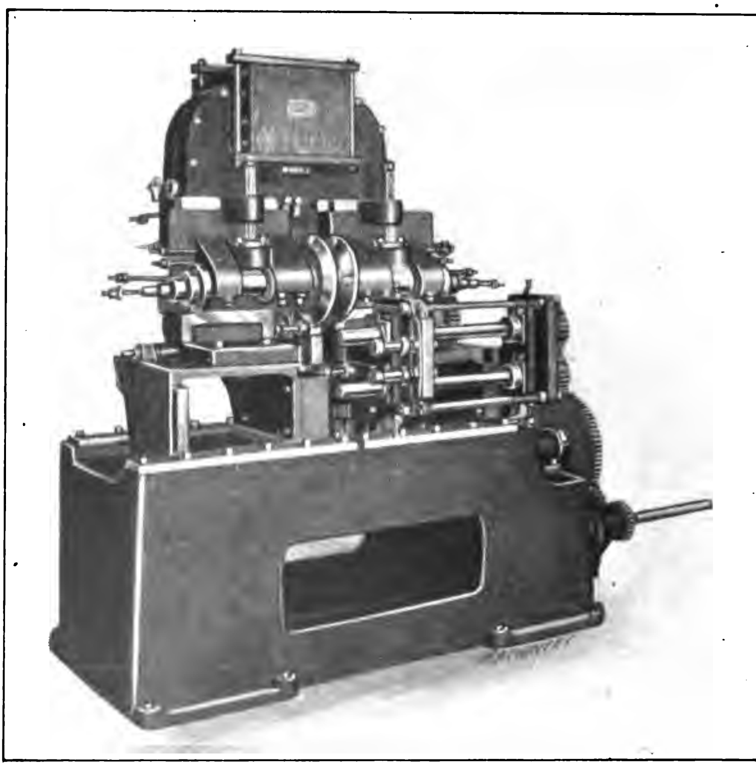


Fig. 8. Special Butt-seam Welder built by the Thomson Electric Welding Co. for Seam-welding Tubing at the Rate of from 20 to 30 Feet per Minute

the seam of the tube and through the adjacent edge of the tube to the other disk, and so back to the turns of the secondary, forming a complete circuit. With this machine, a continuous traveling weld is made, as shown at *B*.

A seam-welding machine embodying the principles illustrated by the diagram at *A* in Fig. 7 is shown in Fig. 8. In this case

the feeding rollers, which are located in a horizontal instead of in a vertical position, have been dismantled to show the construction. The pressure rollers are located directly beneath the electrode disks, and supply pressure to butt the edges of the tube together. This machine is provided with an oil transformer,

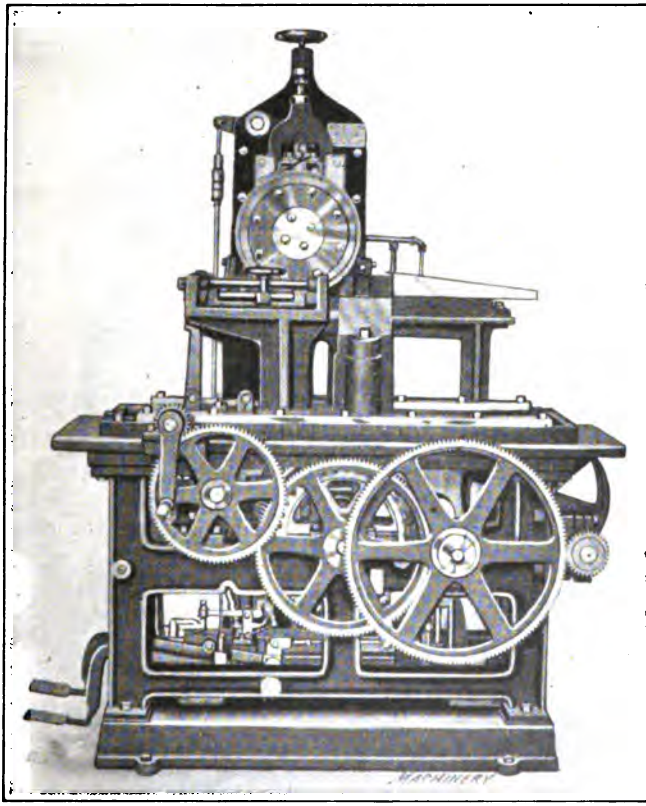


Fig. 9. Special Thomson Electric Seam-welder used principally for Lap-welding Coffee Pots, etc.

and the working terminals are outside the magnetic field. The machine is adapted for welding sheet steel edge to edge to make tubing up to 2 inches in diameter with $\frac{1}{8}$ inch thickness of wall. The speed of welding is from 20 to 30 feet per minute.

A modification of the machine shown at *A* in Fig. 7 is shown

at *C* in the same illustration. In this case the machine is adapted for the seam-welding of flat sheets. The only change is the elimination of the rollers *c* for applying pressure to the tubing and the substitution of small rollers *d* and a flat table *e*. Rollers *d* press the abutting edges of the work together, and at the same time feed it past the welding electrode disks. A weld made in this machine is shown at *D*.

Machine for Lap-welding Household Utensils. — Fig. 9 shows a special seam-welder which is employed principally for lap-weld-

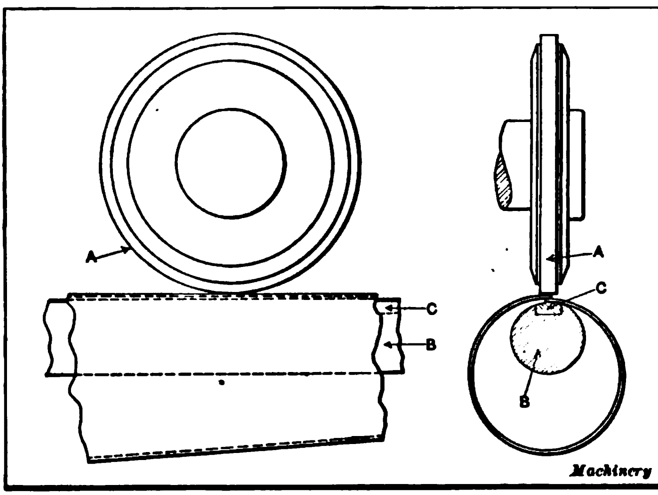


Fig. 10. Diagram illustrating Method of lap-welding Coffee Pots on Machine shown in Fig. 9

ing coffee pots and similar articles. This machine, as shown by the diagram, Fig. 10, has one disk electrode *A* which is used for carrying the current and applying pressure, and a horn *B* with a copper strip *C*, which forms the other electrode. The work to be welded is placed on horn *B* with the joint lapped, as shown.

The machine is then started by operating one of the foot-treadles shown in Fig. 9, and the welding commences. The platen carrying the horn is driven forward by power at the rate of 25 feet per minute and is returned by operating the handle shown at the front of the machine. The maximum length that can be welded in this machine is 12 inches.

Manufacturing Seam-welded Tubing.—As has been mentioned, tubing is made by several different processes. One method is to pierce a heated billet, and then, by successive redrawing operations, form this into a tube of the required length and diameter. Another method is to roll out sheet metal into the form of a skelp, bend it into a tube, and electrically or autogenously weld the seam where the two edges meet, either in the form of a lap- or a butt-weld. The third method, and the one which will be described in detail here, is to take the heated skelp directly from the furnace and weld it electrically without any additional heating or annealing. This method has been patented by Elias E. Ries, and makes use of a rolling machine in connection with a series of electrodes for uniting the heated skelp; the original heat remains in the skelp after it leaves the furnace, being increased to such a point that fusion between the edges of the tubing is possible.

The diagram shown at *A*, Fig. 11, illustrates in a general way this process of manufacturing tubing. Referring to the illustration, *a* represents the bull-head or skelp finishing mill, *b* and *c* the skelp bending rolls, and *m* the guiding bell through which the bent skelp is fed into the several sets of current conducting shoes or contact rollers; each set consists of a number of upper contactors *d* that are in electrical connection with one pole of the heating circuit; also two side bearing contactors or rolls *e* that are in electrical connection with the opposite pole of the heating circuits. The secondary terminals of the heating transformers *f* are connected with the contactors *d* and *e* through the insulated roller-supporting frame-work mounted on the cover of the transformers, the sets of contactors for each transformer being connected in parallel. Another guiding bell is shown at *g* that has a tapering throat which brings the highly heated edges of the partially opened skelp toward each other, so as to close it into tubular form preparatory to welding by rolls *h*. Between these rolls passes a mandrel *i*, shown at *B*, supporting the skelp. The welded tube passes directly from the rolls *h* to the finishing and reducing rolls *k*, which have a smaller mandrel *l*. The rolls *k* give a higher finish, and practically produce a seamless drawn tube from the welded pipe.

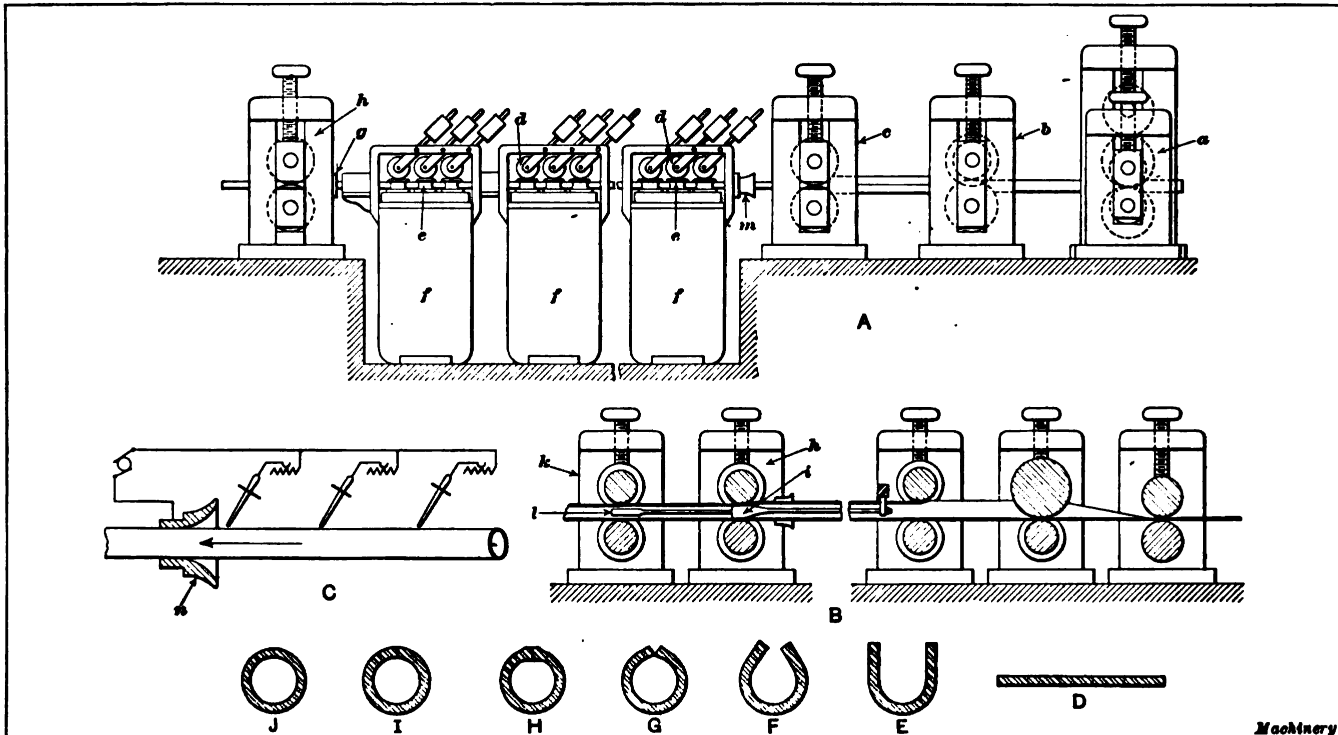


Fig. 11. Diagram illustrating Special Electric Welding Process used in converting Skelp to Electrically Welded Tubing in One Continuous Operation at the Rate of 400 Feet per Minute

Another adaptation of this method of electric welding is shown at *C*, where a series of electrodes form an electric arc and are arranged in tandem along the meeting edges of the tubular skelp. The current passing through these electrodes is independently adjustable by means of a special resistance, and the skelp, when properly heated, is welded in its passage through the welding bell *n* which constitutes the opposite terminal of the heating generator. The longitudinal movement of the frame carrying the electrodes can be varied so as to alternately increase or diminish the heating effect on the metal, depending upon whether the arc travels with or against the direction of the travel of the skelp. By arranging the heating electrodes in this manner, overheating and burning of the skelp is avoided.

The views from *D* to *J*, inclusive, show the sequence of operations performed to convert the material from skelp to tube form. The skelp leaves the furnace at a white heat, and after passing through the various operations up to point *F*, will be found to still retain a temperature varying between 2100 and 2200 degrees F. This residual heat represents about four-fifths of the heat required for welding, so that the heat which it is necessary to add to the abutting edges of the tubular skelp is only about one-fifth of the total; hence, to weld the hot traveling skelp, the transformers are called upon to increase the temperature of the edges of the skelp from 500 to 550 degrees F. Usually the skelp travels at the rate of about 6 feet per second, but by this method it has been found practicable to weld skelp at rolling speeds averaging 400 feet per minute. Continuous lengths of tubing, 60 feet in length, have been electrically heated and welded in from nine to ten seconds.

Electric Riveting. — Electric riveting is accomplished in a machine resembling the spot-welder, provided with a number of modifications to facilitate the setting of rivets. Electric riveting in its simplest form is done with two opposing copper electrodes, the center lines of which coincide. One of the electrodes — usually the upper — is movable vertically. The lower one is made to fit the head of the rivet and the upper one is made to the proper shape and size for upsetting the protruding end of the rivet.

There are several methods of riveting in an electric welding machine, one of which is illustrated diagrammatically in Fig. 12, in which *A* represents the upper movable copper electrode, and *B*, the lower stationary electrode; *C* is the rivet, and *D*, the plates to be riveted together; *A* and *B* are the terminals of the secondary winding *E* of the transformer, and *F* is the primary winding of the transformer, from which leads are brought out to connect to the lines, the switch *G* being interposed to make and break the circuit. After the rivet is inserted through the plates and the stock is in position, the electrode *A* is moved down lightly against the end of the rivet. The current is then turned on by closing

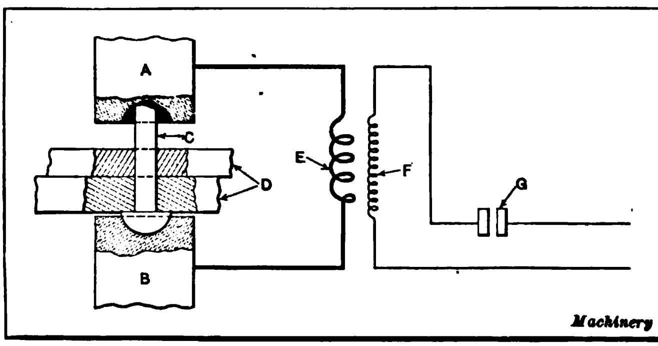


Fig. 12. Diagram illustrating Application of Electric Spot-welding Machine for Electric Riveting, showing Electrical Connections

switch *G*. The current induced in the secondary winding *E* flows directly through rivet *C*. This current is adjusted so as to cause the rivet to become heated quickly. As soon as the proper temperature is reached, switch *G* is opened, cutting off the current, and at the same time a greatly increased pressure is applied to electrode *A*, which upsets the rivet and forms a head shaped like the recess in the electrode.

The heating of the rivet is done so rapidly that there is little loss by radiation or conduction. Therefore, the plates *D* do not produce much chilling effect, and the rivet is heated throughout its length. For this reason, when increased pressure is applied to electrode *A*, the rivet is upset in the hole in plates *D*

and fills the holes tightly. Even in the extreme case shown in Fig. 13, where there is considerable clearance between the rivet and the hole, the hole is effectively filled by the rivet and a tight joint secured. The heating is done fast enough to prevent the formation of scale, which is always found on rivets heated in a forge fire, and the maximum strength is, therefore, insured. Further, there is no overheating or burning of the rivet. Fig. 14 shows a rivet in the process of upsetting. This illustration shows that there is a gradual bulging and folding of the fibers. The use of an air hammer results in breaking up these fibers somewhat, and, hence, reduces the shearing strength of the rivet.

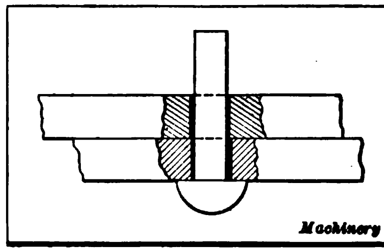


Fig. 13. Extreme Case of Difference in Size between Hole in Sheet and Diameter of Rivet — Electric Riveting effectively closes this Clearance Space

Electrodes for Electric Riveting. — Both the upper and lower electrodes are made of copper when the rivet to be upset is quite small — say, up to and including $\frac{3}{8}$ inch in diameter. When the rivet is larger than this, the pressure necessary to upset it is

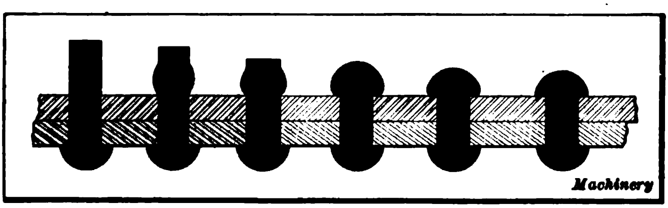


Fig. 14. Sequence of Operations in upsetting a Rivet in Electric Welding Machine

sufficient to destroy the upper electrode in a short time, if it is made of copper. On machines for upsetting large rivets, therefore, it is necessary to use a harder material, usually steel, for the upper die. Steel, however, becomes quite hot in carrying the current, and this destroys its temper. To overcome this difficulty, machines of recent design carry two upper operating mem-

bers, one a copper electrode for heating and the other a steel die for upsetting the rivet.

Fig. 15 illustrates, diagrammatically, the modifications necessary in an electric welding machine for upsetting large rivets. The upper movable head carries a copper electrode and a steel die. These are held in a copper slide, which is pushed in or pulled back, depending upon whether the rivet is to be heated or

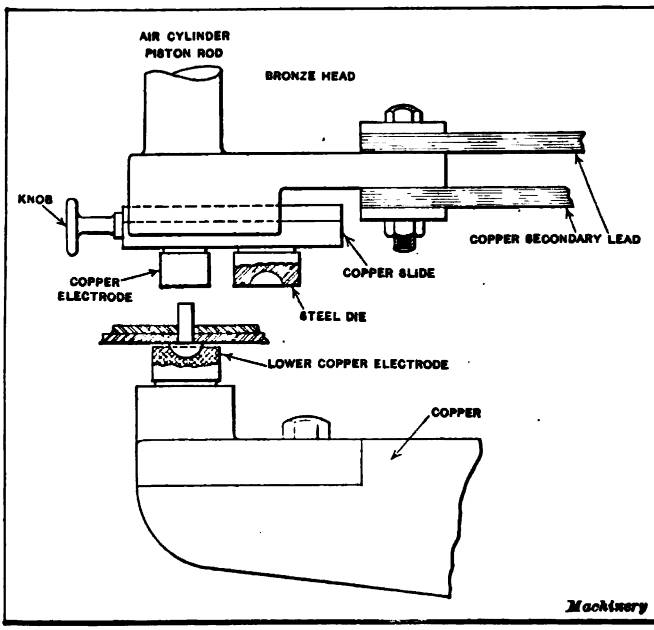


Fig. 15. Method of upsetting Rivets over 3/8 Inch in Diameter, using Copper Electrodes for Heating and Steel Die for Upsetting

upset. Any suitable means may be employed for locating these two members in the desired position when in operation on the work. The copper electrode constitutes one terminal of the secondary circuit and serves to carry the current to the rivet. It is applied to the end of the rivet with just sufficient pressure to insure electrical contact. When this is done and the rivet has attained the proper temperature, the slide is withdrawn, bringing the steel die into position in line with the rivet, and then pressure is applied to upset the rivet.

Upsetting Large Rivets. — A simple means of operating an electric welding machine, and one that is frequently made use of for applying the two pressures — for electrical contact and for upsetting — is a cylinder supplied with compressed air. This

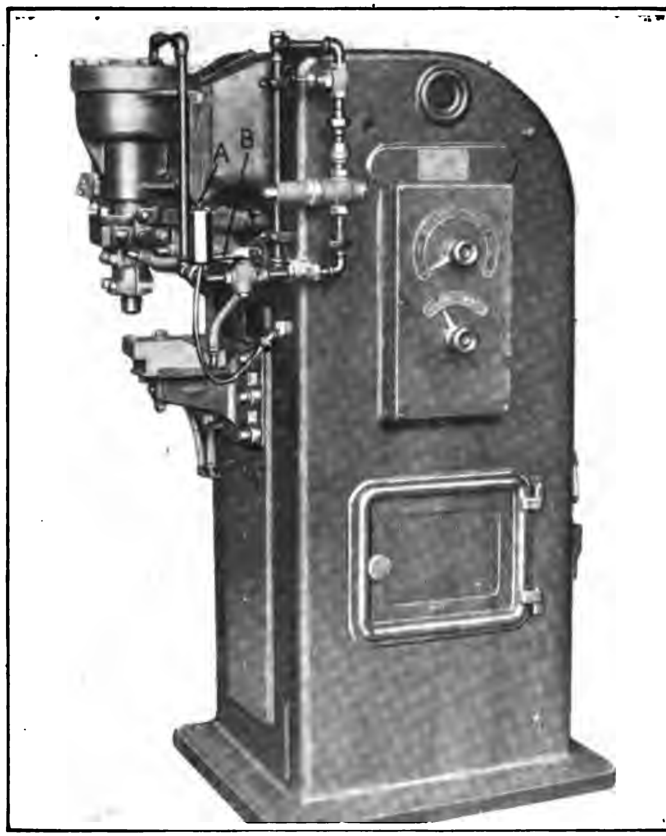


Fig. 16. Special Electric Welding Machine fitted with Air Cylinder and Three-port Valve for Operating Electrode and Steel Riveting Die — Steel Riveting Die not shown in Position

is provided with a valve having three ports. One port connects directly to the air line and admits air into the cylinder at high pressure (from 60 to 80 pounds per square inch). The second port admits air at low pressure (from 5 to 20 pounds per square inch) to the cylinder. The low pressure is secured directly from

the high-pressure piping by means of a suitable reducing valve. The third port in the valve allows the cylinder to exhaust and the steel upsetting die to return to its original position. The valve is provided with a handle which moves in a horizontal plane

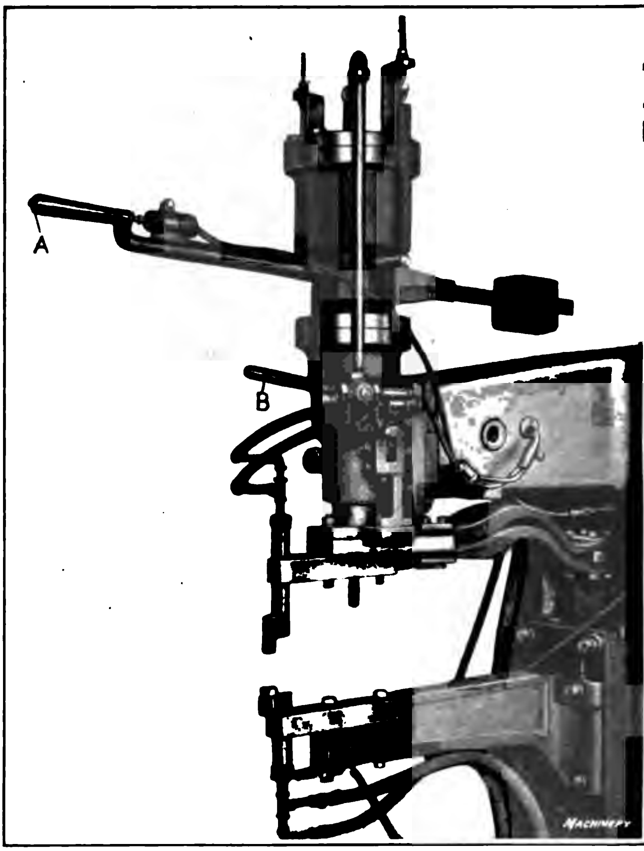


Fig. 17. Electric Welding Machine fitted with Air Cylinder for Riveting

through an angle of 90 degrees; this movement is sufficient to connect the cylinder with any one of the three ports. A small push-button switch *A* mounted on the valve handle *B*, Fig. 16, serves to control a remote solenoid switch for handling the welding current. Reference to Fig. 16 will show that the complete cycle

of operations is taken care of by the right hand of the operator, which leaves the other hand free to handle the work. Inasmuch as all plants doing riveting use compressed air, the advantages of this type of machine are apparent. When air pressure is not available or desirable, the machine may be driven by a belt or motor and employ the well-known punch-press action. Electric riveters have also been built for manual operation or for a combination of manual and some sort of power operation, as shown in Fig. 17. In a machine of this type, the left hand is used to bring the electrode lightly against the rivet, and the current is controlled by thumb pressure on push-button *A*. When the temperature is correct for upsetting, the right hand is used to turn the valve handle *B* to admit air under pressure to the cylinder.

Advantages of Electric Riveting. — A number of machines are now in successful operation in the United States which have shown quite a saving over the older methods of riveting and, in addition, make a tighter joint. In some cases, one machine has taken the place of five men using air hammers. Except for the slight flash which results when contact is made, electric welding machines make no noise, and are quiet as compared with air hammers.

The actual time taken in one plant using these electric riveting machines for setting $\frac{5}{16}$-inch rivets was $1\frac{1}{2}$ second, and the electrical energy used, 15 kilowatts. This means 2400 rivets for 15 kilowatt-hours. At four cents per kilowatt-hour, the actual cost for current is sixty cents, or, roughly, one cent per 40 rivets. Variations in the size of rivets would cause a corresponding variation in these figures, but they serve to give some idea of the cost. Electric riveting machines are now used by automobile manufacturers for riveting the chassis frames, gear housings, differential and rear axle casings, and for similar work. Gear rims are riveted to their spiders and structural arm sections are riveted together by this method.

CHAPTER V

PERCUSSION WELDING

PERCUSSION or percussive electric welding, which is one of the latest developments in the electric welding art, was originated by L. W. Chubb of the Westinghouse Electric & Mfg. Co., East Pittsburg, Pa. During the year 1905, while Mr. Chubb was experimenting with electrolytic condensers and rectifiers in the research department of this company, he noticed that wires could be connected to aluminum plate by the condenser spark when the cells were discharged. It was also noticed that copper wires could be attached to aluminum or that two pieces of aluminum could be joined by the condenser spark. The joint thus made, however, was not strong, but after a careful consideration of the results of these early tests, it was decided to try out this method of welding with a greater condenser discharge.

This method of electric welding was first applied to the welding of aluminum, because this metal had given such trouble in soldering, especially when joining small wires. With the substitution of aluminum wire for copper wire, for many electrical purposes, which has taken place in the last few years, the need for a good means of joining aluminum has become urgent, and the percussive electric method was developed primarily for this purpose after a thorough investigation of the methods available. In addition to the welding of wire, several other special applications have been successfully made, so that a general review of some of the more important points should be of interest. Percussive electric welding differs from the resistance method chiefly in the nature of the current used. For resistance electric welding, alternating current is used, whereas, for percussive welding, direct current is employed. It is possible to weld any two metals, whether alike or different, of high or low melting

points, or of an unequal thermal conductivity. In the ordinary welding of aluminum, the oxide which covers the surface of the pieces being welded prevents the metals from flowing together after the ends have been melted in the usual way. Large wires and rods of aluminum can be welded by melting the metal under the oxide film, and then suddenly pushing the ends of the pieces together, breaking the oxide film and allowing the clean metal to flow together, but on small wire this practice is not feasible.

Development of Electric Percussion Welding. — Following the experiments made in 1905, Mr. Chubb designed a condenser giving a discharge on a larger scale, and employing the same principle of simultaneous condenser discharge and percussive engagement that had been used in the original experiments. During the test and development of the welding apparatus, however, it was found that the best results depended upon several variables, such as the condenser capacity, the velocity and force of impact, the voltage, and the resistance and induction in the circuit. The first apparatus consisted of two hinged arms with wire grips in their ends. Wires placed in the grips were connected to the terminals of a charged electrolytic condenser. Upon being released, these arms were drawn together and at the instant of contact of the wires, the condenser discharged, and the force of impact welded the ends together. This apparatus was not very satisfactory, as it did not allow of a separate study of the effect of the variations in velocity, momentum, kinetic energy, etc. A second apparatus similar in construction to a pile driver on a small scale was then built. This was provided with one stationary and one movable wire grip or chuck. In this apparatus the "forge effect" and velocity could be varied independently by a separate adjustment of the length of drop and mass of the moving parts. Other welding tools have been designed in which springs are used to "shoot" the wire-holders together horizontally, but this type of device has not been as satisfactory as the "drop-hammer" type.

Construction of Percussion Welding Apparatus. — A percussive welding device of the portable type is shown in Figs. 1, 2, and 3. Fig. 1 shows this device set up for welding a copper

wire to a coil of aluminum wire, and Fig. 2 shows plan and sectional elevations of the device. Referring to Fig. 2, it will be seen that this machine has a base *A* carrying two parallel uprights *B*, which are held together at the top by stationary head *C*. Sliding on these guides *B* is a carriage or head *D* which carries a clamping chuck for holding one of the pieces of wire to be welded. In order to support carriage *D* in a raised position, adjustable trip *E* held on the rod *F* is provided. Trip *E* contacts with trip *G*, held in the sliding head *D*, and is insulated from it. Rod *F* is so located in its bearings that it can be rotated to bring trips *E* and *G* into alignment with each other. Both trips *E* and *G* are beveled, enabling carriage *D* to be raised, but not lowered until trip *E* is released by a slight rotative movement of the rod *F*, which is again returned to its operative position by means of spring *H*. The wires *I* and *J* to be welded are held in chucks *K* and *L*. Clamping chuck *L* has the general form of a spool or flanged cylinder, and is split longitudinally into two parts which are grooved to receive one of the wires to be welded. The chuck is mounted in a slot in the base of the machine and is held in position and also caused to grip the wire by a thumb-nut. The clamping chuck *K* is similar to *L*, and is held in the same manner. The other wire *I* which is to be welded is conducted down through the top

Fig. 1. Portable Percussive Electric Welding Machine

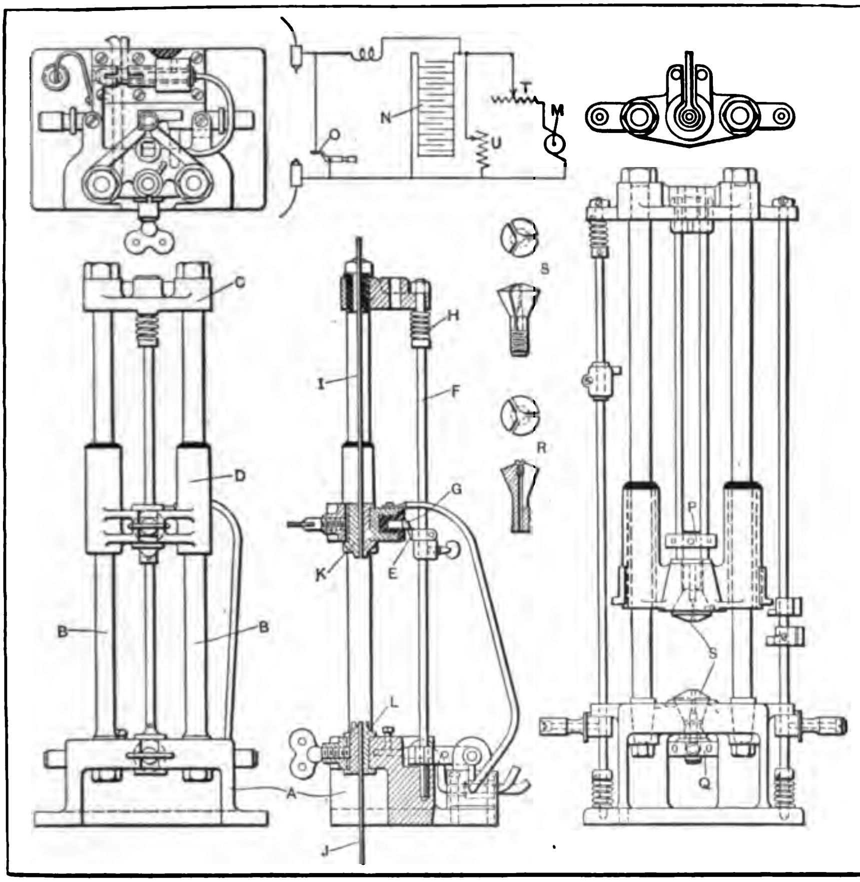


Fig. 2. Front Plan and Sectional Elevation of Portable Percussive Electric Welding Machine and its Connections — Two Types of Machines Illustrated

cap of the machine as illustrated, and passes through an insulating bushing.

The electrical energy is supplied from a generator *M*, or any source of direct current, which charges the electrolytic condenser *N*. There is a high resistance *T* in the circuit, and the condenser charge can be varied by resistors *T* and *U*. In operation, the pieces of wire *I* and *J* to be welded are secured in the chucks *K* and *L* so as to project out from the chuck for a short distance. The carriage *D* is then raised to the desired height, which is determined by the setting of the trip *E*. The position

of trip E is governed by the diameter and composition of the wire to be welded. After the wire has been clamped in position and trip E properly set, switch O is opened to permit generator M to charge condenser N. Trip E is then released from trip G, allow-

Fig. 3. Complete Percussive Electric Welding Outfit, comprising Electric Welding Machine, Rheostat, Electrolytic Condenser and Connections

ing the carriage to drop and carry the end of the wire I into percussive engagement with the end of wire J. At the instant of contact, the condenser N is discharged, and the energy thus concentrated at the point of contact is sufficiently great to produce

heat for a perfect weld between the wires. The weld is then complete, and after being removed from the machine, the wire will be found to have the same strength at the joint as anywhere else.

A percussive electric welding machine embodying the general principles just described, but of slightly different construction, is shown to the right of Fig. 2. In this machine the tripping mechanism is guided by two rods instead of one, and it is also provided with a different type of work-holding chuck, which is shaped similarly to that used on a screw machine and is also split to allow for expansion and contraction. The chuck body is tapered to fit into a correspondingly shaped hole in the base and sliding head of the machine, and is tightened on the work by means of nuts *P* and *Q*. The jaws of these chucks may be threaded as shown at *R* to adapt them to receive small screws if desired. By supporting a screw in this manner in the lower chuck and holding a section of platinum wire in the upper chuck, the screw may be easily provided with a platinum tip. Each of the chucks has a pin projection which engages a notch in the holder for the purpose of preventing the chuck from rotating when the nut is being tightened.

Description of Percussion Welding Process. — The action that takes place when the wires are percussively engaged covers such a short period of time that it is practically impossible to see it with the naked eye. The only possible way of analyzing the action is to consider it from a theoretical standpoint. From careful observation of a large number of welds and the study of oscillogram records, the action that takes place between the engaging terminals of the rods to be welded is graphically shown in Fig. 4. At *A* the wires to be joined are shown close together as they appear when approaching each other. It will be noticed here that the ends of the wire have been provided with chisel-shaped edges, arranged at right angles to each other. This is done so that the first engagement between the two wires is at a small point. These chisel-shaped edges require no particular care in making, and in fact the thin edge usually produced when wires or rods are cut off with an ordinary pair of pliers or shearing device is satisfactory.

At the instant of contact, *B*, the voltage of the circuit falls away as shown by the curve *a*. The current and power, on the other hand, increase rapidly as indicated by curves *b* and *c*. In this particular case, the voltage drops from approximately 207 to 160 volts in 0.0001 second and reaches zero at the end of 0.00035 second. The power expended in the circuit rises from zero to 23,000 watts in 0.0001 second, and then almost as suddenly

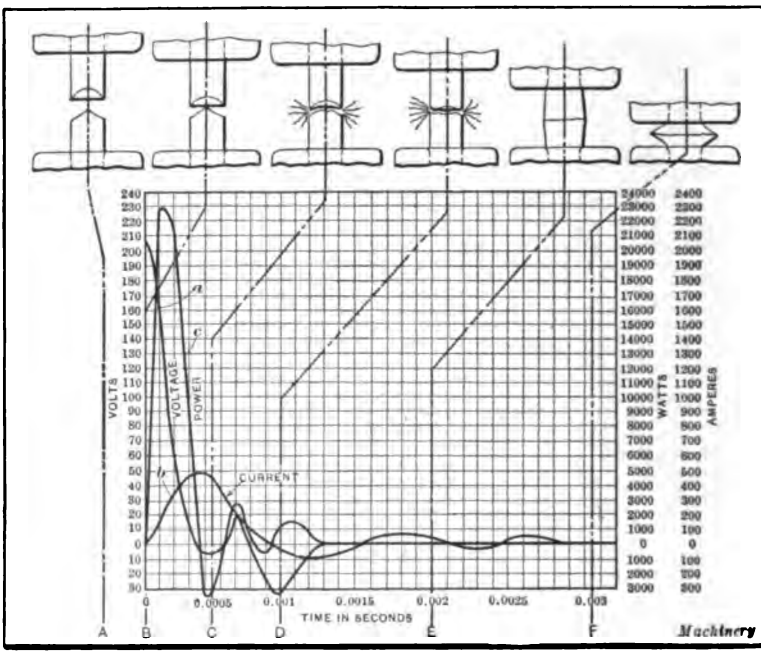


Fig. 4. Oscillogram Chart illustrating Power consumed and Time taken for Making Electric Welds by Percussive Engagement

decreases, crossing the zero line with the voltage. The weld in this case is completed electrically, that is, so far as a perfect junction of the two metals is concerned, in 0.0012 second, although the upsetting action still continues to forge the metals together until the upper chuck is brought to rest. Although 23 kilowatts is being dissipated between the ends of the wire at a certain instant, the total energy used at the weld is only 0.00000123 kilowatt-hour, or enough to light an ordinary 50-

watt 16-candlepower lamp for 0.09 second. The cost of this amount of energy at ten cents per kilowatt-hour would be twelve-millionths of a cent. Referring to Fig. 4, it will be noticed that the watt curve *c* oscillates, and that the negative value would indicate a return of stored energy. Such an action would be impossible from a metallic arc, but can be explained by the fact that the voltage was measured above and below instead of between the wire chucks, so that the storage and return of energy is from the magnetic flux produced in the steel chuck set up by the current of 500 amperes flowing through them.

The time between the first contact and the finished weld is of such short duration that the exact action cannot be recorded, but is supposed to be about as shown in Fig. 4. At *A*, the wires are approaching each other at a velocity of about from 65 to 200 centimeters per second (25 to 80 inches, approximately). At *B*, the first contact is made, at which time the current begins to build up and heat the small section of metal carrying the current. At *C*, the ends of the wire have separated, not by any appreciable retarding or reversing of the motion of the upper wire, but by the melting and vaporizing of the metal which first came into contact. At *D*, the wire chucks are closer together, but the arc is still burning between the wires. At *E*, the second contact has been made, the arc extinguished, and the upsetting of the metal has begun. At *F*, the complete weld is shown after the upper chuck has come to rest and the upsetting is completed.

The generation of heat is so localized, so sudden, and so intense that there is no time for unequal heat conduction through the shanks of the wire, and the ends will be melted and even vaporized whether the melting point of the metal is high or low. For this reason, various metals and alloys can be welded together independently of their electrical resistance, melting point, or heat conductance. All the combinations of metals or alloys that have been tried will weld, but the joints will not be permanent with such combinations as aluminum and tin, or lead and iron.

Although the action of percussion welding is complex, as indicated by the chart, Fig. 4, it is not necessary to construct

the welding apparatus or to adjust its parts with more than an ordinary degree of accuracy. Furthermore, it is not necessary to be very careful about determining the capacity of the condenser, the voltage of the charging circuit, or the inductance of the welding circuit. As an example, perfect welds have been made on the first trial between such metals as tin and platinum, platinum and nickel, and copper and aluminum, without special precautions, calculations or adjustments. While the machine is relatively light, a sufficient compression is obtained to forge the terminals of the metals to be welded, and by the use of a condenser of suitable design and capacity a sufficiently intense heat is supplied for a fraction of a second to melt the engaging surfaces and weld such metals as platinum and tin without injury to either metal.

It is believed that such a tremendous amount of energy relative to the size of the conductors not only fuses the engaging surfaces but vaporizes them, thus actually separating the solid portion of the wires for an instant as shown at *C* in Fig. 4. At this stage of the welding action the terminals of the wire being welded are surrounded by a metal vapor. That this is true is abundantly proved by deposits of metal particles found on the chucks of the welding machine after a number of welding operations have been performed. It is believed that metal vapor surrounds the terminals before they are brought into permanent engagement, and that this is one of the reasons why successful joints have been secured between such unlike metals as aluminum and copper and between two aluminum conductors, the surfaces of which become oxidized with extreme rapidity when exposed to the air under ordinary welding conditions.

Nature of the Work Produced by Percussion Welding. — It has been found that, on account of the intense heat that can be concentrated at the desired point for a short period of time, the electric percussion method is particularly effective in making a satisfactory joint. The effect of the concentration of energy referred to on an aluminum wire is to vaporize a small quantity of the aluminum on the engaging surfaces, thereby blowing out laterally in all directions the vaporized material, and carrying off,

or at least breaking up, the oxide film which has hitherto prevented the welding of aluminum successfully. In the welding of copper to aluminum by the percussion method, it would be expected that the joint would be unsatisfactory, owing to the fact that certain combinations of these metals form a brittle alloy. This, however, is not the case, as welds between these two metals are so ductile that they may be worked in a die, and forged or rolled into thin foil. Any alloy that is formed at the junction of the aluminum and copper wires must range from 100 per cent copper on one side to 100 per cent aluminum on the other, but possibly the brittle combinations are so thin that the joint as a whole is flexible and ductile. The possibility of making satisfactory joints between aluminum and copper is of great commercial importance, as copper feed wires which solder easily can be welded to aluminum coils. It was thought at first that a weld of the two metals would result in a brittle joint, but tests show that after four years the joint is apparently as strong and ductile as when first made. Similar ductility has been noted in almost every combination of metals when first welded, but disintegration and loss of ductility eventually result in such welds as silver to tin or aluminum to tin; the welds are effected by what is known in the trade as " tin disease " or " tin-pest" — a disintegration of the molecules.

Metals which are either hardened or softened by heating and sudden cooling may be welded together without appreciable change in the physical properties of the material. Tempered spring steel wire welded and reduced to a uniform diameter and tested has shown equal strength at or near the weld without any noticeable change in temper. Metals such as hard drawn copper, silver, aluminum, etc., can be welded without causing any local annealing, and these metals, as well as soft steel, can be welded together without detrimental local hardening. In welding unlike metals by the ordinary method of electric welding, a brittle alloy is sometimes formed between the joints of the metal. In percussion welding this is not the case, as the energy and heat are so concentrated, and continue for such a short interval, that there is no appreciable flowing of one metal into the other, the

line of demarkation being very sharp, even when the welded pieces are rolled out into a thin sheet or foil. If a film of alloy is produced at the joint, the film is so thin that it is flexible. This is true of various combinations of metals, as will be described later.

Microscopical Examination of Welds. — Several explanations are given for the mechanical properties of various metals before

Fig. 5. Microphotograph of Copper and Aluminum Wire electrically welded showing Intermingling of Metals — Magnified 850 Times

and after welding; some of these are: First, such a sudden heating and cooling may not allow time for a change in molecular structure; second, with hard steel, the heated metal at the weld is so suddenly cooled by conduction of heat into the adjacent cold metal that it is again hardened; third, with hard copper, silver, aluminum, etc., the heating and sudden cooling would ordinarily soften the metal, but the cold upsetting of the

blow in welding possibly hardens it again; fourth, the metal subjected to the sudden heating and cooling may be hardened or annealed (depending upon the characteristics of the material welded), but the amount of material affected may be too small to be detected.

As an example, in welding No. 18 (0.0403 inch in diameter) hard-drawn aluminum wire, 0.00123 watt-hour is dissipated at

Fig. 6. Microphotograph of a Copper-aluminum Weld — Magnified 850 Times

the weld. Assuming that none of the energy is lost in noise, radiation, or metallic vapor and that one-half of the total is propagated in a heat wave in each direction along the wire, it can be shown mathematically that an annealing temperature will not be reached more than 0.05 millimeter (0.002 inch) from the weld. The total amount of metal softened would be a disk 0.1 millimeter (0.0039 inch) long and 1.02 millimeter (0.0403 inch)

in diameter. A soft insertion of such proportions could hardly be detected.

In welds between some metals diffusion takes place, but in any of the useful combinations the change is too slight to affect the ductility of the weld. The welds, as a rule, show a sharp dividing line between the metals, but there is often an intermingling of the two at or near the center for a short distance.

Fig. 7. Microphotograph of a Copper-silver Joint showing Sharp Line of Demarkation at Point of Weld—Magnified 1000 Times

Figs. 5 and 6 show a new weld and a three-year old weld between aluminum and copper. The microphotographs, which are enlarged 850 times, were taken at the irregular point in the weld; elsewhere the line of division is sharp and rather straight. In addition to the small irregularity of the dividing line, some spots of bright material, possibly aluminum-copper alloy, are present at this point, but do not appear at other points in the weld.

Both of these welds are so malleable that they are capable of being rolled into thin foil. Wire having such welds was used in actual service at a temperature over 100 degrees C. (212 degrees F.) carrying a heavy direct current, and did not show any signs of deterioration in its mechanical properties. The heating current was maintained for weeks and tests were made with the current flowing in both directions. The microphotographs,

Fig. 8. Microphotograph of a Copper-platinum Weld — Magnified 1000 Times

Figs. 7 and 8, show copper-silver and copper-platinum welds, respectively. Both of these welds show a sharp dividing line when enlarged to 1000 diameters. The weld, Fig. 8, is three years old.

It has been found that the electrical resistance of two wires welded together is not appreciably increased by the small film of high resistance alloy at the joint formed in welding. Tests on eighty-five alternate pieces of aluminum and copper wire

joined with eighty-four welds, making a total length of 23.5 centimeters (9.254 inches) showed an increase of 0.56 per cent in resistance in three years. The increase is small and may be due to a change in the joints, or error in observation, or oxidization. This sample was recently rolled and showed no change in malleability.

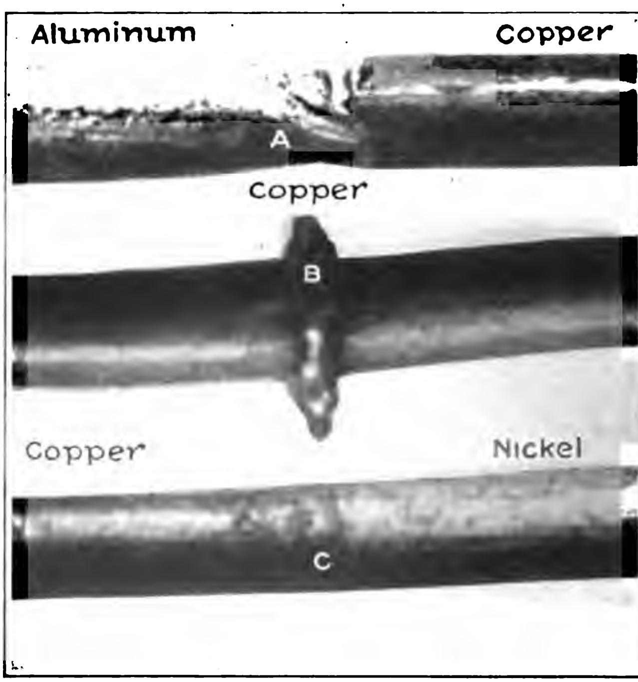


Fig. 9. Nickel, Copper, and Aluminum Wires united by Percussive Electric Welding, showing Condition of Metal at Welded Joint

Metals that can be Percussively Welded. — Thus far, no difficulty has been experienced in welding any metal or alloys of metals nor, in fact, any combination of metals or alloys. The following are a few of the combinations that have been welded: Tin to aluminum, copper and platinum; lead to tin; tin to platinum; tin to copper; nickel to platinum; steels of various carbon contents; and various alloy steels. The chief advantage of the percussion method of welding at present is in

the uniting of copper and aluminum, since it is almost impossible to make this weld with the other well-known methods, and when made by the resistance method the joints are as brittle as glass. Another interesting feature of the joint made in wires of different materials by percussion welding is the fact that the metal is just as ductile at the weld as it is at any other place along the surface. Fig. 9 shows various combinations of metals that have been percussively welded. At *A* is shown a piece of aluminum wire welded to a piece of copper and subsequently reduced by drawing the wire through a die. The aluminum

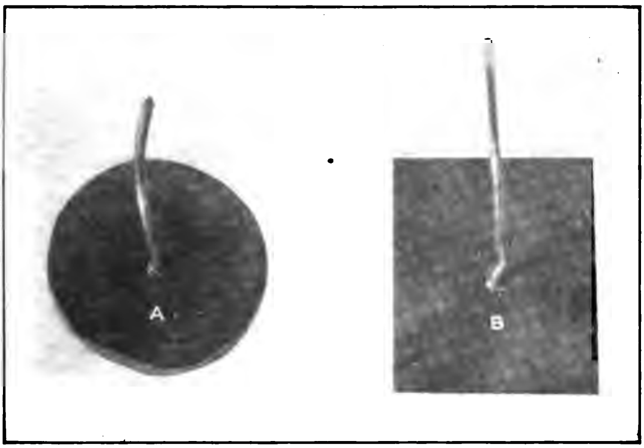


Fig. 10. Examples of Butt-welding Operations performed by Percussive Electric Welding Apparatus

wire has "disintegrated" to a certain extent at the joint, but is still firm. This wire has been magnified eighteen times. At *B* is shown a joint of copper to copper with a flash. When this flash is removed, it will be possible to draw the wire without showing any change in shape or reduction in diameter at the joint. The reason for this is assumed to be that the action of welding is of such a nature that the fused or volatilized metal is completely expelled and the cold metals come together to form the joint with a very thin film between them. At *C* is shown a piece of copper wire welded to nickel. It will be noticed that when the wire was drawn there was practically no difference in

diameter at the joint between the copper and nickel wire. This has been magnified eighteen times.

Examples of Percussive Welding. — While the development of this method of electric welding was brought about primarily to secure successful joints between aluminum and copper wires, it is evident that it possesses wide application. Metals varying widely in characteristics, such as platinum and tin, may easily be welded, from which it follows that almost any metal can be joined where the joint is within the capacity of the machine.

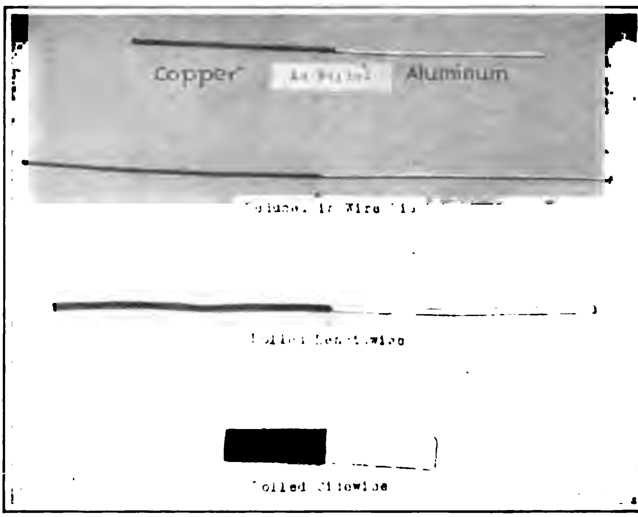


Fig. 11. Examples of Aluminum-copper Welds on Wire manipulated to show Ductility and Malleability of Weld

The apparatus up to this time has only been made for welding wires 0.072 inch in diameter and smaller, but there is no reason why, with a larger machine and suitable apparatus, wires much larger than this could not be welded, as well as other classes of work. Sufficient experimenting has been done to show that the welding of wires to plates or blocks can be successfully accomplished. Fig. 10 shows two examples along this line. At *A*, a piece of $\frac{1}{32}$-inch copper wire has been electrically butt-welded to a piece of brass $\frac{1}{32}$ inch thick; at *B*, a piece of $\frac{1}{32}$-inch copper wire has been butt-welded to a piece of $\frac{3}{16}$-

inch sheet copper. In the ordinary method of electric welding, it would be practically impossible to join these two pieces for the simple reason that the area of one is so much greater than the other that the wire would fuse and melt away before any perfect junction could be secured. By means of percussive welding, this operation is comparatively simple and a joint is made that is as homogeneous and strong as the metal itself.

In order to determine just what effect manipulation of the stock would have on the welded section, copper and aluminum wires, as shown in Fig. 11, have been welded, drawn and rolled. The first view shows copper and aluminum wires welded together; in the second view, these two pieces of wire have been reduced in diameter by drawing; in the third view, the wire has been

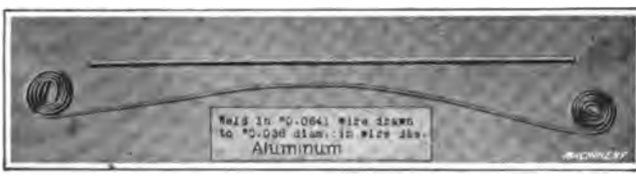


Fig. 12. Sample of Aluminum Wire welded and drawn through Die without Disintegration at Joint

rolled out lengthwise; and in the fourth view, a section of this wire is shown rolled out sideways. A study of these metals under different manipulating processes is interesting. It will be noticed in the first view, that the joint is almost straight across the wire, but after drawing, the aluminum wire, which is slightly softer than the copper wire, has been reduced a little at the joint, and the copper wire has overlapped the aluminum wire in one place. This same condition is shown in the third view where the copper has rolled into the aluminum. Probably the most interesting condition is shown in the fourth view where the wire has been rolled sideways. Here it will be seen that the line of demarkation between the aluminum and the copper wire is extremely sharp and that it is practically straight across the section, showing that the two metals came together when practically in a cold state and that the film of fused metal between them must have been extremely thin.

In order to show the ductility of metals when percussively welded, two pieces of aluminum wire were joined as shown in Fig. 12. This piece of aluminum wire, which was 0.0641 inch in diameter after welding, was then drawn down to 0.036 inch in diameter through a wire die. The point at which the weld was made could not be determined even under a microscope, which showed that there was no physical change in the wire due to welding and that, as far as ductility was concerned, the metal was just as ductile at the weld as it was any other place along the

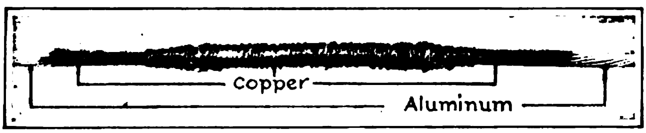


Fig. 13. Method of splicing Aluminum Cables

section. Another interesting use of this art is shown in Fig. 13. This illustrates a method of splicing aluminum cables. This is done by welding a short length of copper to each strand of the aluminum cable, and then twisting or wrapping the copper wire around the joint, and soldering the ends. After the joint is soldered, an aluminum tube is placed over the joints.

There are also many uses of the percussion method in the jewelry trade, where it can be employed for joining platinum without showing any solder line; welding sterling tips to table forks without annealing; welding pins to badges; and many other similar applications. The attaching of contact points of platinum, tungsten, silver, etc., for various electrical purposes, is also readily accomplished.

CHAPTER VI

ELECTRIC SOLDERING

THE application of electricity in welding has been explained in the preceding chapters. As stated, there are two fundamental methods of welding in which the electric current is employed, *i.e.*, the arc and resistance methods. The arc is used to a limited extent for welding large broken parts and its application is considered more economical than any other process, but the danger of handling current at the high voltages that are necessary makes its scope limited. The other welding process, as invented and developed by Dr. Elihu Thomson, consists of causing a heavy current of electricity at a low voltage to flow through the abutting ends of the pieces of metal to be welded. This heats the metal at the joint to a welding temperature.

What is true of welding is also true of the electrical soldering process about to be described, as in both processes heat is developed by the same action, *i.e.*, the passage of a large current of electricity through the joint. This soldering process is a mechanical one and in operation the apparatus used is not likely to give any more trouble than any simple machine will. The wear on the clamping jaws makes it necessary to replace them periodically, but as they are comparatively inexpensive and constitute the only replacement necessary, the operating expense is very low. As described in the following, the process is especially applicable to small work, like that of optical frames or watchmaking. The amount of the current used in optical framework averages 1 kilowatt-hour per 1500 joints. This current can be purchased from the local lighting company, or a generator can be installed which would probably reduce the current expense in case a very large amount of this work is done.

Procedure in Electric Soldering. — The general method of soldering consists of holding the pieces to be joined by clamping

jaws with the ends of the work in firm contact. A heavy current of electricity, regulated to heat the joint sufficiently to melt the solder, is next passed through the work. The solder, in the form of tape or wire, is then applied to the joint. It flows in and around all parts heated to the proper temperature, as when using a gas flame, but an important difference is noted: the "life" or temper is retained in pieces that have been electrically soldered, instead of their being left in an annealed condition as when heated with a flame. One theoretical reason for this is based on the fact that the core of the work does not heat to a temperature

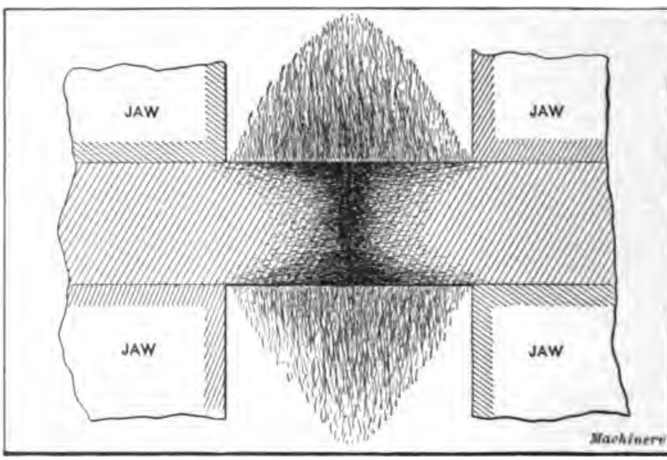


Fig. 1. Diagram showing Relative Volume of Work that is heated by the Current

sufficient to become annealed. This condition is illustrated in Fig. 1. The heat varies from a maximum at the joint to the normal temperature of the machine at the jaws, and the heated section would take some such form as shown. As the length of the work that is heated is relatively short, the distance between the clamps usually being twice the diameter of the work, the heat has not had time to run into the work before the joint is made and the current shut off. This is shown by the fact that two highly tempered wires soldered together by the electrical process offer the same resistance to being bent at any other point

as at the joint. The yield point or bending strength of the metal is practically as high as before heating.

Range of Electric Soldering. — Practically all of the metals such as brass, copper, steel, German silver, gold, and silver can be soldered successfully in this way, and it is without doubt the most economical method for a continuous run of work. There are no noxious fumes or smoke produced in making an electrically soldered joint, and windows can be opened in warm weather without affecting the process in the least. The operator is thus able to do a full day's work every day, instead of experiencing the fatigue that is caused by breathing the carbonic acid gas caused by the gas flames. The joint is made almost instantly, the time required to heat the joint, apply the solder, and shut off the current being approximately from three to five seconds, depending upon the cross-sectional area of the joint. As the gripping jaws of the holders are made as large as possible, the heat is drawn from the work almost the instant that the current is shut off, allowing the work to be removed immediately.

Electrically Soldered Optical Frames. — A few samples of parts of eyeglass frames joined by this process are illustrated in Fig. 2. At the extreme right is shown a "cable-temple" before and after the joint is made. These cable ends are wound in a special machine and consist of two coils, right- and left-hand, one inside the other. The inner coil is made of brass wire wound on a steel wire arbor and then swaged to a specified diameter. The outer coil is made of German silver, gold filled, or any other stock that is desired, and is pushed over the inner coil. After the assembled cable is soldered to the "temple," which is a solid wire with the center reduced, it is swaged to the final finished diameter. This leaves a very smooth and flexible ear-piece, and at the same time a stiff connection to the lens-holders. The soldering of the brass-German-silver cables caused some trouble through the brass fusing before the German silver would heat enough to flow the solder, but this was remedied by using a larger wire in making the secondary coil of the transformer.

Two specimens of "nose-pieces" soldered to "eyes" are shown to the left of the cable-temples. These eyes are formed

by rolling a round wire to form a groove in it; they are then wound on an arbor and sawed apart. The end-pieces are sawed, assembled and peened in one machine. Formerly they were soldered by gas. Previous to soldering on the "bridges" by electricity, a long space was annealed on the eyes. This made a joint that could be easily bent, and various methods of striking in dies were resorted to in order to regain some of the temper. In all cases of soldering by electricity, the eye wire is left with nearly all of the original temper. Another eye with studs at-

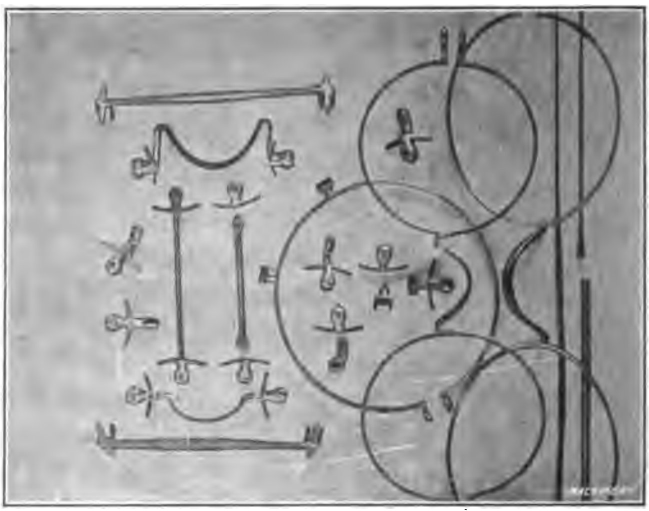


Fig. 2. Examples of Eyeglass Parts joined by Electrical Soldering

tached is shown encircling samples of "straps," "studs," and "end pieces" before and after assembling and soldering, and to the left of this eye are shown different forms of bridges and nose-pieces with straps, before and after soldering. Parts that have about the same cross-sectional area at the joint are very easily handled.

Utilization of High-voltage Alternating Current. — In the process of electrical soldering, alternating current is invariably used. For mechanical and economical reasons, direct current is not to be considered. To make this clear, suppose a joint

having a cross-sectional area of 0.125 square inch requires a current of 130 amperes at 3 volts to heat it properly, and that an ordinary plating dynamo rated at these figures is used to furnish the current. It will be noticed that the work heats entirely from jaw to jaw. Then suppose a joint having a cross-sectional area of one-half the first one, or 0.063 square inch, is to be heated by the same dynamo. A suitable resistance must be interposed in order to reduce the current to a point where the joint will heat properly without melting. This resistance will use current as if it were doing useful work, and the small joint will cost practically the same as the large one, as regards the amount of power consumed. On the other hand, it is claimed that the heating action of alternating current is more uniform; the heat is more intense on the surface and is evenly conducted to the core of the pieces, offsetting the effect of radiation and conductance.

The current used for electric soldering should be a single-phase alternating current of any frequency between 40 and 60. A step-down transformer of the shell-core type is preferably used to reduce the 110- or 220-volt pressure down to the $1\frac{1}{2}$ to 5 volts required at the machine jaws. A pressure of from $1\frac{1}{2}$ to 5 volts is sufficient for all optical frame work, and from 75 to 500 amperes of current is consumed. The use of a large transformer for small work is wasteful, as, although the current can be regulated as desired without much loss of energy, the work heats more slowly than when a transformer of the proper capacity is used. The machine transformer is usually connected in series with a single-phase generator, but it may also be connected to one phase of a poly-phase circuit, or to either phase of a two-phase generator.

Transformer. — The transformer is made by winding a coil of very large insulated copper wire around a core built up of iron sheets cut to shape by dies, each sheet being insulated from the other by shellac or some other medium. This coil, known as the secondary coil, is carefully insulated from the primary coil, which consists of a large number of turns of smaller wire wound around the secondary coil and its core. The number of turns of fine wire depends upon the number of turns of heavy wire and

the current to be taken in and given out. The type of transformer illustrated in Fig. 3 is particularly well adapted for use in electric soldering, as it can be used without changes with other work-holders; and this would not be the case if it were built into the machine. As shown, it has the coils protected by an iron cover which not only acts as a case, but also as part of the magnetic field. Transformers of this type are very efficient — from 95 to 97 per cent of the current taken in being given out — and they are particularly well suited for constant work.

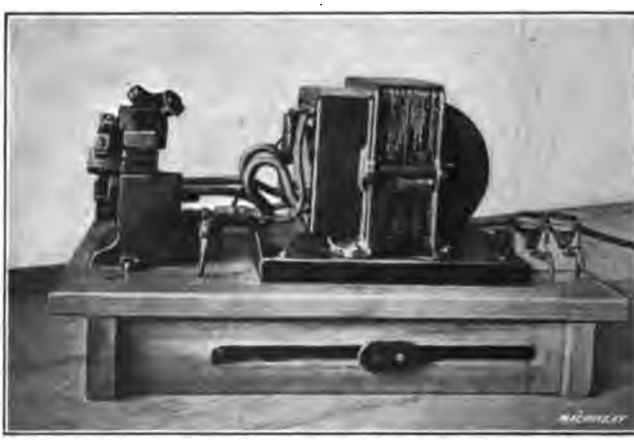


Fig. 3. Example of Unit Equipment for Soldering Optical Frames

Unit System of Electric Soldering. — The "unit system" of soldering may be applied very successfully in the manufacture of optical frames. This system consists in mounting all the working parts of the machine for each particular operation on a base-board or stand. Figs. 3 and 4 illustrate this idea; the transformer is mounted at the center, with a fuse box at the rear and the work-holder at the front of the board. Under the base-board is located the adjustable rheostat operated by a sliding plate shown at the side. To set up this machine anywhere in the shop, it is only necessary to run two wires from the feed circuit and attach a foot-treadle to operate the clamp jaws and switch. This system allows the same transformer and other parts

to be used with another machine in case of a change, or the discarding of the original machine.

There are two practical methods of controlling the heat obtained at the joint; one is by introducing an adjustable rheostat into the primary circuit, as illustrated; the other method is to introduce a reactive or " choke " coil into the same circuit. Of the two, the reactive coil is undoubtedly the better, as there is practically no loss of power and an infinite number of adjustments may be made, whereas the rheostat is limited to the number of contact points used. The difference in loss of current is an inappreciable amount, however, and as the rheostat is cheaper, it has been used more than the choke coil. Rheostat control is characterized by its simplicity, the ease with which it may be built, and the simplicity of operation.

Fig. 4. Closer View of Work-holding Jaws shown in Fig. 3

Machine for Soldering. — A machine for soldering straps to eye-pieces and bridges is shown in Fig. 5. This machine or holder consists of a base *A* with a vertical slide *B* working in a slot at the rear. A second slide *C* also works in another slot at the rear, the slot being inclined at 45 degrees to the base. This slide *C* is operated through a lever *D* which receives its movement from the slide *B*; the lever *D* is pivoted in the base. The slide *B* is provided with a spring tension which allows the lever *D* to keep a constant pressure on the slide *C* while the slide *B* continues to move. The lever *D* works in a slot cut through the

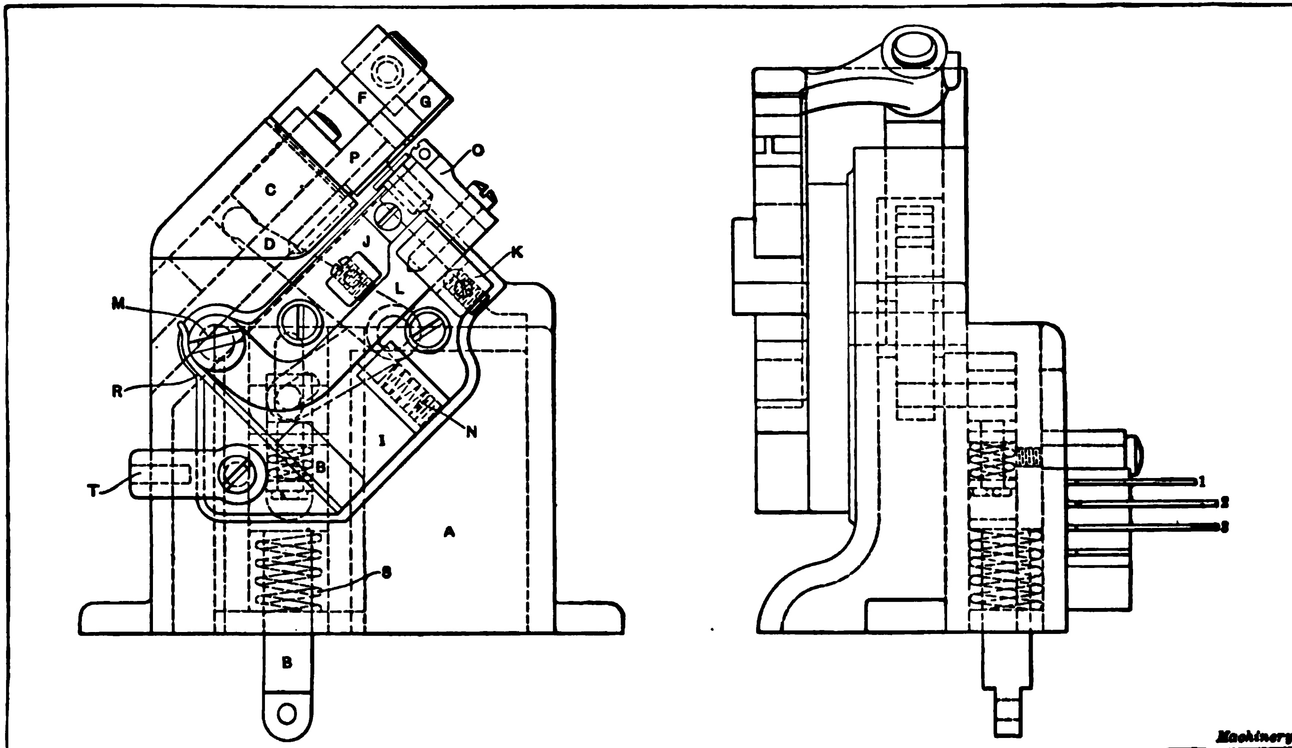


Fig. 5. Machine for Soldering Straps to Eye-pieces and Bridges

slide C, this slide carrying a cam-operated swinging arm at its upper end to which the clamping jaws G are attached. This upper jaw is designed to swing away from the work and leave it clear to facilitate handling.

At the rear of the machine and attached to the base there is a switch which is operated by a pin in the slide B. At the front of the base and insulated from it is the casting I which is milled to receive an arm L that is free to move on a pivot, but the motion of the arm is limited by the adjusting screws J and K. The arm is held against the screw J by means of an adjustable spring tension N. There is a jaw O at the upper end of the arm, which, in this case, holds the strap in the proper relation to the other part to which it is to be soldered. The contact of the jaw O with this strap is made by the pressure of the spring N against the arm L, and the strap is held against the part to which it is to be soldered, which is carried between the jaws P and G. The jaws are made interchangeable for different classes of work.

At the lower end of the casting I, one end of the secondary or low-pressure circuit is connected by means of the terminal T, and a spring-brush R is used to insure a low resistance contact between the casting I and the rocker arm L. The lower clamping jaw P is attached to the base A and the jaw is provided with a gage for aligning the part held in it. The slide B is held at the top of its movement by means of the spring S. Two points of the switch control the primary or high-pressure circuit, and the other two points operate on the secondary which is in the circuit with the jaws of the machine. The contact points at the switch are made of silver, in preference to copper. A chain connects the lower part of the slide B with a foot-treadle which is placed under the bench in a convenient position for the operator.

Operation of Soldering Machine. — The operation of this holder is as follows: The two pieces to be joined are covered with a non-scaling or protective mixture; the joint end of one piece is also dipped into the flux. They are then assembled in the proper relation to each other in the jaws of the holder, which are so arranged that the rocking arm is away from its stop when the work is in place. The foot-treadle is then de-

pressed until the upper clamp jaw grips the work; in this case, only one part is held rigid. The other piece — which is a strap — is guided by its form and a teat on the piece held in the rigid jaws. The solder, in the form of wire, is then placed on the junction and the foot-lever depressed further until the current is connected. Almost instantly the solder flows and runs around the joint, when the foot-treadle is released entirely, and the work, which is left free, is taken out with a pair of tweezers. On work which is very small and difficult to handle with the fingers, tweezers are used; but such work as soldering temples, bridges to eyes, bridges to straps, or eyes to studs is handled with the fingers. The heat is held at the joint instead of spreading as it

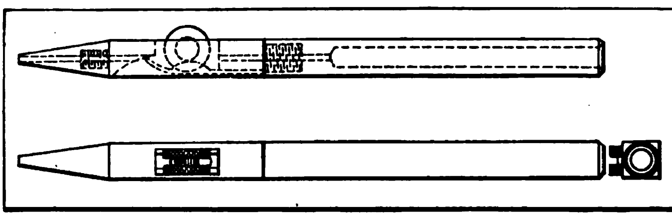


Fig. 6. Holder for Applying the Solder by Hand

does when heated with the flame, so that it causes the operator no discomfort to take out the joined pieces as soon as the jaws are opened. The jaws are brushed clean at intervals, using a stiff bristle brush for this purpose.

The spring tension jaw was developed after considerable trouble had been caused by particles of dirt or burrs getting into the junction, as well as by not having the two ends fit together properly to form a contact of low resistance. By the movable jaw, all of this trouble was eliminated, as the constant spring pressure holds the ends in firm contact, automatically keeps the ends together in the case of burrs or other points fusing, and prevents any break in the contact while the current is being applied. In the welding process, the ends are forced together while at a welding temperature, but this changes the form of the ends and shortens the pieces; consequently, it could not be applied to optical work, as there must be no change in the size or form of

the pieces to be joined. The spring behind the rocking arm *L* in Fig. 5 is adjusted to provide just sufficient tension to keep a constant pressure on the junction without deforming or upsetting the ends, thus forming the joint when the ends become hot. The jaws of the holder are made as large and heavy as possible to allow of their working continuously without heating. These jaws are made of copper, which has been found best for this purpose on account of the low resistance of the contact made between them and the metal to be operated on.

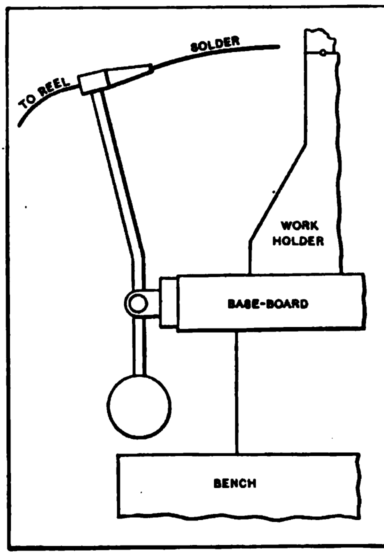


Fig. 7. Bracket for Supporting Solder Holder on the Machine

Preparing the Work to Prevent Scaling. — To prevent gold-filled metal from scaling or "burning" at the joint, it is customary to cover the work with some preparation to prevent oxidation. Probably the best, and at the same time the simplest, method of preparing the work is to place it in an ordinary flour sieve, cover it with commercial boracic acid, and then shake out all loose powder. This leaves the parts covered with a thin coating of dust which becomes liquid at a low red heat and prevents the air from coming into contact with the surface of the gold. Another method is to make a solution of the boracic acid and water, dip the pieces into this solution, drain off the surplus, and allow them to dry. In no case, however, should any solution be used that will leave a hard film over the parts, as this would prevent a clean contact with the clamping jaw, create a resistance that would cause an arc to develop, and spoil the surface of the work. The flux generally used is borax and is prepared in the following manner: A piece of genuine slate — the green colored variety,

which is the hardest, being the best — is thoroughly cleaned; a few drops of water are placed in the center and a thick, creamy mixture of borax is made by rubbing a piece of crystalline borax in the water on the slate until the desired consistency is obtained. The proper mixture is best determined by actual trial; a mixture that is too thin or too thick will either cause the solder to remain in one spot, instead of flowing through the joint, or create an unclean contact and interfere with the heating.

Holder for the Solder. — The solder in the form of wire may be held in the hand in a holder, as shown in Fig. 6, or some arrangement such as the one shown in Fig. 7 may be employed. This consists of a chuck at the top of a wire, bent about as shown, and having a metal ball at the lower end heavy enough to balance the wire and chuck in an upright position. This wire is held by a screw in one member of a universal joint, which allows the chuck to be moved freely to any position in front of the clamping jaws and take a convenient position to allow the solder to be grasped by the operator. When a holder of this type is used, both hands are free to place and adjust the work and apply the solder quickly.

CHAPTER VII

PRINCIPLES OF ELECTRIC ARC WELDING

The general principles and processes of electric arc welding are described in Chapter I. In the present chapter the details of the process will be dealt with. Various kinds of welding outfits will be described and instructions for their operation given. In addition, a number of examples of work performed by the arc-welding process will be illustrated and described. The electric arc-welding process is particularly applicable to certain classes of work such as the reclamation of defective castings in foundries, repair work in railroad shops, and the welding of new work in tank and boiler shops, steel mills, locomotive shops, and shipyards. As mentioned in Chapter I, there are a number of different methods that have been devised, but of these only three, and in general practice only two, are of sufficient importance to require detailed treatment. These are the Bernardos or carbon electrode welding process, the Slavianoff or metallic electrode welding process, and the Zerener process, which latter is used only to a limited extent.

Principle of Electric Arc Welding. — The principle involved in arc welding consists chiefly in the heating of the work to be welded to a welding heat by means of an electric arc produced or struck (1) between the work itself and a carbon electrode, as in the Bernardos process; (2) between the work itself and a metallic electrode, as in the Slavianoff process; or (3) between two carbon electrodes, as in the Zerener process. When carbon electrodes are used, a metal rod is nearly always employed for feeding additional material into the joint to be welded. When a metallic electrode is used, this electrode is made from a metal which itself is suitable for feeding into the joint to form the material required to complete the weld. It is generally conceded that, where applicable, the arc welding process is cheaper than the oxy-acetylene or oxy-hydrogen welding processes.

The Electric Arc. — An electric arc is formed when a current of electricity passes from one conductor to another through a gas or vapor which has been brought to incandescence by the discharge of electricity. The conductor from which the current passes into the incandescent gas or vapor is known as the *positive electrode*, while the conductor to which the current passes is called the *negative electrode*. It is estimated that approximately 75 per cent of the resistance offered to the passage of a current of electricity from the positive to the negative electrode takes place at the positive electrode. The remaining 25 per cent of the resistance takes place in the medium between the electrodes and in the negative electrode. It is generally believed that the negative electrode offers more resistance to the flow of current than does the gas or vapor between the electrodes in the short arcs that are used in the arc welding process. As the amount of heat in the arc or electrodes is proportional to the amount of resistance offered to the passage of the electric current, it is evident that the visible arc or flame produces a comparatively small percentage of the total heat of the arc; by far the largest part of the heat is produced on the positive electrode, at the point where the arc impinges.

The Carbon Arc. — The system of electric welding which makes use of a carbon (or graphite) electrode is often known in the shop as *carbon arc welding*. The electrode is a rod of carbon or graphite between which and the work the electric arc is drawn until the work is heated to the point of fusion. This method is used for three principal purposes. Its first and most important use is for cutting or burning off metal of iron or steel parts, which is the simplest application of the electric arc. It is frequently used for reducing scrap material to sizes capable of being easily handled, and for cutting risers and fins from large castings in foundries. Some manufacturers of electric welding apparatus, however, do not recommend it for general use for cutting structural steel, as cutting of materials in which there are no blowholes can be more neatly and cheaply done by the oxy-acetylene or oxy-hydrogen torches; but in cases where a small amount of cutting is to be done and an arc welding outfit is on hand, it

provides a convenient means for doing this kind of work, and the method is especially applicable for the cutting off of pieces in preparing repair work for welding. The second application of the carbon arc is for the welding of very heavy work by the use of heavy currents and large electrodes, and its third application, which is very limited, is in the welding of brass. In each of these two latter cases, a rod of suitable metal must be introduced into the arc, so that the weld can be built up by the adding of welding material. The metal supplied may be either a rod held in the operator's hand or may consist of small pieces of scrap material which are fused, so that they will unite with the part of the work that is already raised to a molten state by the arc, thus forming a solid mass of even structure upon cooling.

The principal field for the carbon arc for welding is in foundries and steel mills for the repair of imperfect or broken castings of large size. The loss from imperfect castings of large size is always high, but can be reduced to a very small percentage by the use of the arc-welding processes, as castings containing blow-holes, cracks, etc., can be readily repaired at small expenditure for material and labor. For all work in which the carbon arc is used, comparatively heavy currents are required, ranging from 200 to 1000 amperes. Owing to these heavy currents, the heat can be applied quickly and can be concentrated at the required point until a very intense heat is reached and the process of either cutting or welding becomes very rapid. However, the carbon arc is not used anywhere nearly as extensively as the metallic arc, for reasons that will be explained in the following paragraphs.

Polarity for Carbon Arc Welding. — As already mentioned in Chapter I, the work is made the positive electrode and the carbon, the negative electrode. Two advantages are gained in this manner: (1) Particles of carbon from the electrode are not carried into the weld, and (2) the greater portion of the heat of the arc, being concentrated at the positive terminal, heats the metal to be welded more rapidly.

The Metallic Arc. — In the Slavianoff process, commonly known as the *metallic* or *metallic arc* welding process, the metallic

electrode — usually made from a soft grade of iron or steel of some special composition, or from bronze for the welding of bronze objects — is brought into a fused state by the heat of the arc, and metal from it is gradually deposited at the point of the weld, at which point the work itself is raised to a state of incandescence, so that the metal from the metallic electrode unites intimately with it. The operation of welding by this method is very rapid, as the softening or melting of the electrode is continuous after the arc is started, and thus the weld is quickly filled with the filling material. The method is extensively used in all classes of repair and reclamation work, as, for instance, in the filling of cracks and blow-holes in castings, in the building up of worn parts of rolls, rails and locomotive wheel tires, in the repairing of cracks in boilers and locomotive fireboxes, in marine repair and construction work, and in many other industries where it is used as a manufacturing method for increasing the speed or convenience with which the finished product may be brought out. Examples of manufacturing work in which the arc-welding process is applied are found in the welding of heads and branches to tanks, in the joining of the seams of tanks and boilers, in the welding of fireboxes, flue sheets, boiler tubes, in the manufacture of steel cars, and in the welding of automobile bodies, rear axle housings, universal joints and other automobile parts, as well as in all classes of pipe and sheet metal work. About 90 per cent of all electric welding is done by the use of metallic electrodes.

The metallic electrode process does not require as heavy a current as the carbon arc. The maximum current required is about 200 amperes. For this reason, it is slower than the carbon electrode process, and the metal is deposited less rapidly. It is deposited more uniformly, however, and a weld made by a metallic electrode is stronger and has a smoother and more regular appearance than a weld made by the carbon electrode; hence metallic electrode welding is employed when the strength of the weld as well as its appearance are of importance.

Polarity for Metallic Arc Welding. — On account of the fact that the heat of the positive electrode is greater than that of

the negative electrode, the work is made the positive electrode, while the metallic electrode is made the negative terminal. In this way, the piece to be welded, which generally has a much larger mass than the welding electrode or wire, and which, therefore, loses more heat by conduction, is still enabled to heat rapidly. In some cases, as in the welding of very thin sheet metal, the welding wire is made the positive electrode in order to reduce the tendency of the arc to burn through the sheet metal. It is only when welding thin sheets by the metallic arc that it is desirable to use the metal electrode as the positive pole. In carbon arc welding, the carbon electrode must always be the negative pole, as otherwise carbon is carried over from the electrode into the weld, causing hard spots, brittleness, and unsatisfactory results.

Combination of Metallic and Carbon Arcs. — In some cases, especially in repair work, it is necessary to remove some parts of the metal to be welded at the place where the weld is to be made. It may be necessary, for example, to cut out part of a burnt, broken or worn spot in order to insert new material, or to widen a crack in order that the metal from the electrode may be properly deposited in it. As the cutting operation must be performed by means of the carbon arc, the combined use of the carbon and metallic arcs is often desirable, the carbon arc being used for cutting, and the metallic arc for the subsequent welding. Preheating of large castings may also be done in this way, as a large section of the work may be raised to a high temperature by using the carbon arc, after which the actual welding is performed by the metallic arc. The strains in the welded parts are more evenly distributed on account of the preheating, and welds of greater strength are thus obtained.

Carbon Electrodes. — The carbon electrodes may be made either from a high grade of homogeneous, uncored, hard carbon similar to that used in arc lamps, or from graphite. The former are generally known as "carbon electrodes," while the latter are termed "graphite electrodes." Carbon electrodes are cheaper, but disintegrate more readily. The end of the electrode should be rounded off, but care should be taken not to

bring it to a sharp point. In some cases, tapered electrodes are used. The carbon or graphite electrodes used vary in size from $\frac{1}{4}$ to $1\frac{1}{2}$ inch in diameter. The following have been found, by trial, to be approximately the proper values of current for different sizes of carbon electrodes: $\frac{1}{4}$ inch in diameter, up to 100 amperes; $\frac{1}{2}$ inch in diameter, from 100 to 300 amperes; $\frac{3}{4}$ inch in diameter, from 300 to 500 amperes; and 1 inch in diameter, from 500 to 1000 amperes. Graphite electrodes may be used with higher current values. They are not extensively used, however, because they are more expensive. The filling material used with carbon electrodes should be of the same kind and quality as the material being welded, except that a somewhat higher percentage of carbon in the welding material is desirable, inasmuch as some of the carbon is burnt out in the welding process.

Metallic Electrodes. — The size of the metal electrode used varies with the nature of the work and the current required, but it is ordinarily made from $\frac{3}{32}$ to $\frac{5}{32}$ inch in diameter. It is necessary in every case to have a proper relation between the current strength and the size of the electrode, because the heat of the arc must be sufficient to raise a spot on the work nearly to the point of fusion, in order that there may be an actual union of the metal from the electrode with the work. Unless the temperature is high enough for this union, the weld will be imperfect and the metal from the electrode will not join properly with that of the work. On the other hand, if the metal is heated to too high a temperature, there is danger of burning it and oxidation also takes place more rapidly, thus impairing the weld. In addition, greater heating and cooling strains are set up in the weld. The current, therefore, must be regulated to produce a proper temperature rise in the work, and the size of the electrode must be so selected, that there is no danger of overheating or oxidizing the metal when deposited. On the other hand, the electrode must not be too large for the current used, as this would produce an imperfect union, the fusion being slow and imperfect and the welds unsatisfactory.

Metallic electrodes for welding steel or iron are obtainable

from supply houses generally, from makers of steel and iron wire, or from the various companies that manufacture electric arc-welding equipment. The electrodes used in connection with practically all welding equipments consist of rods from $\frac{1}{16}$ to $\frac{1}{4}$ inch in diameter and about 12 inches long; the largest size of electrode is used for cast-iron welding only.

The Wilson Welder & Metals Co. supplies metal electrodes in sizes of from $\frac{1}{16}$ to $\frac{9}{32}$ inch in diameter, the standard size being gage No. 9, which is approximately $\frac{5}{32}$ inch in diameter. These electrodes are furnished in five different grades, suitable for boiler repair, steel welding, cast-iron welding, filling castings, and bronze welding, respectively. Experience has shown that in order to secure satisfactory results in electric welding, the use of a proper grade of metal is of as great importance as having a properly designed machine. Recognizing this fact, the Wilson Welder & Metals Co. has developed specially prepared welding metals that are not adversely affected by the heat of the arc. These metals are used in the form of an electrode. This metal is a homogeneous alloy combined with an excess of manganese to compensate for losses while passing through the electric arc, thus insuring a substantial amount of manganese in the welded joint, which is essential to its toughness. In addition, a manganese-copper alloy welding electrode has been developed, which is composed of iron homogeneously combined with such an excess of manganese and copper over the amount lost in the arc as will insure to the welded joint an additional degree of toughness and ductility, and at the same time will leave it soft enough to be machined.

The C & C Electric & Mfg. Co. states that, with the company's constant-current low-voltage (16 to 20 volts) system of electric welding, electrodes of Swedish iron (mild steel) are best for all-around welding of steel. They can be used for welding overhead work, as well as vertically (as, for instance, in the welding of flues), without any of the limitations encountered when using electrodes that fuse at an unusually low temperature. One of the great advantages of Swedish iron welding electrodes is that the material always may be depended upon to be uniform.

The Lincoln Electric Co. furnishes metallic electrodes $\frac{1}{8}$, $\frac{5}{32}$, and $\frac{3}{16}$ inch in diameter, used as follows: The smallest electrode is used on sheet metal $\frac{1}{8}$ and $\frac{3}{16}$ inch thick, and also for welding flues into flue-sheets in locomotive shops. The $\frac{5}{32}$-inch electrodes are more generally used than any other size, and are employed for boiler-plate welding in general. The $\frac{3}{16}$-inch electrode is used principally for "building up," as, for example, in the building up of worn parts of steel castings. It may also be used for welding when speed is more important than the quality of the work.

The Westinghouse Electric & Mfg. Co. recommends the use of electrodes of practically the same dimensions for the same purposes as stated in the preceding paragraphs.

Current and Voltage for Carbon Arc. — The voltage across the arc varies from 35 to 50 volts, depending partially upon the amount of current being used, but still more upon the length of the arc. The current ranges from 200 amperes up, depending upon the type of work being done. For light work, small electrodes and current values less than 200 amperes can be used. The average type of welding done by the carbon arc requires from 300 to 400 amperes. For cutting, or, more correctly, burning, from 400 to 600 amperes, or more, are required.

Current Required for Metallic Arc Welding. — The current required for the metallic arc is smaller than for the carbon arc and seldom exceeds 175 or, at most, 200 amperes for the heavier classes of work; it ranges from this maximum down to 12 or 15 amperes for thin sheet metal work. The generated voltage varies from 16 to 75 volts, according to the make of the equipment used. Metal electrodes also require smaller voltage than carbon electrodes. The voltage at the arc is ordinarily from about 15 to 25 volts. The current and voltage used in electric welding depend to a large extent upon the size of the metal electrode used, as well as upon the composition of the electrode and the nature of the work to be welded. The metallic electrode can be used on much lighter stock than the carbon electrode, but in welding it requires greater ability on the part of the operator on account of the shortness of the arc and the conse-

quent difficulty of maintaining it. The metallic arc is more unstable than the carbon arc, and the operation is more difficult to master, but this is compensated for by the fact that certain classes of welding can be done by the metallic arc process that cannot be done in any other way, as, for example, the welding of overhead or vertical surfaces.

Data on Current and Voltage. — According to a report submitted to the convention of the Association of Railway Electrical Engineers and reprinted in the *Railway Review*, December 2, 1916, $\frac{1}{8}$-inch mild steel electrodes used for welding 2-inch flues require a current of from 60 to 90 amperes and a voltage of from 14 to 16 volts; 5-inch flues using a $\frac{5}{32}$-inch mild steel electrode require a current of from 110 to 140 amperes with a voltage of from 16 to 20 volts. Mild steel electrodes, $\frac{3}{16}$ inch in diameter, require a current of from 150 to 180 amperes with a voltage of from 18 to 25 volts. When, in cutting, carbon electrodes $\frac{3}{4}$ inch in diameter are used, a current of from 250 to 350 amperes and a voltage of from 35 to 50 volts are required. For cutting with carbon electrodes 1 inch in diameter, a current of from 350 to 500 amperes and a voltage of from 35 to 50 volts are required. In some outfits, however, carbon electrodes much smaller in diameter are used, one company employing electrodes only $\frac{3}{16}$ inch in diameter.

Sheet Metal Welding. — Very thin sheet metal is welded by metallic electrodes with low current values. The General Electric Co. gives the following data for sheet metal welding based on cost of labor at 30 cents per hour and current at 2 cents per kilowatt hour:

Metal, No. 20 gage or less; metal electrodes, less than $\frac{1}{16}$ inch in diameter; current, 10 to 25 amperes; speed, 30 feet per hour; average cost, $1\frac{1}{2}$ cent per foot.

Metal, No. 18 gage to $\frac{1}{8}$ inch; metal electrodes, $\frac{1}{16}$ inch in diameter; current, 35 to 40 amperes; speed, 30 feet per hour; average cost, 2 cents per foot.

Metal, $\frac{1}{8}$ to $\frac{3}{16}$ inch; metal electrodes, $\frac{3}{32}$ inch in diameter; current, 30 to 50 amperes; speed, 25 feet per hour; average cost, $2\frac{1}{2}$ cents per foot.

Metal, $\frac{3}{16}$ to $\frac{1}{4}$ inch; metal electrodes, $\frac{1}{8}$ inch in diameter; current, 50 to 100 amperes; speed, 20 feet per hour; average cost, 3 to $3\frac{1}{2}$ cents per foot.

Metal, over $\frac{1}{4}$ inch; metal electrodes, $\frac{5}{32}$ inch in diameter; current, 75 to 150 amperes; speed, 18 feet or less per hour; average cost, 5 cents and up per foot.

The General Electric Co. estimates that the cost of welding $\frac{1}{4}$-inch plates by the arc welding method is about 50 per cent of the cost of welding similar plates by the oxy-acetylene method. To weld steel plates $\frac{1}{2}$ inch in thickness with the electric arc will cost less than 40 per cent of the cost with the oxy-acetylene process, and for plates 1 inch in thickness, the cost of arc welding is estimated to be less than 15 per cent of the cost by oxy-acetylene welding.

Advantages of Electric Arc Welding. — The following claims of superiority are made for electric arc welding as compared with other methods of welding for materials and conditions for which the method is suitable: First, the high temperature of the electric arc makes it possible to rapidly reduce the metal to be welded to a molten state; the heat being applied rapidly is not carried away from the point of the weld by the heat conductivity of the metal fast enough to lower the temperature at the weld appreciably. Second, the tools for performing the weld are comparatively easy to manipulate and the apparatus required is simpler and easier to handle than that used with gas-welding outfits. Third, for all work, except very thin materials, it is the cheapest welding method available. Fourth, the voltage of the current is so low that the process is perfectly safe, and if the operator is provided with a proper hood or shield to protect him from the light and heat of the arc, he is not exposed to any danger. The heat and light from the carbon arc are much greater than from the metallic arc. Fifth, there is no danger from explosions.

The most important advantage of all, probably, is that welds can be made overhead and on vertical seams by the metallic arc. The arc actually carries the metal particles from the electrode into the weld with considerable force, so that even

with an overhead weld, the metal is forced clear through the space between the adjoining surfaces, welding them securely. Overhead welding can hardly be done by other means, and vertical welding only with great difficulty by other methods. The simplicity of electric welding for overhead and vertical seams is, therefore, one of its strongest claims in many instances.

Metals that can be Welded. — The metals that are most commonly welded by the electric arc are steel, steel castings, and cast iron. For mild rolled steel and steel castings, electrodes or filling rods of soft iron, preferably Swedish iron, are used; tool steel may also be welded with Swedish iron electrodes. For cast iron, rods of cast iron high in silicon are used. Copper has been welded to steel by using a copper electrode, and brass has also been welded with copper electrodes. In the welding of bronze, a bronze electrode is used. Electric arc welding, however, is most successful in the welding of steel, steel castings, and cast iron; but on account of the great heat of the arc, it cannot be used successfully, except by expert welders, for welding cast-iron sections that are thinner than $\frac{1}{4}$ inch. It is not practicable to weld aluminum with the electric arc, the oxy-acetylene process being best for this metal. It is also likely that the oxy-acetylene welding process is preferable for the welding of copper, brass and bronze, although there may be instances when these metals must be welded overhead or along vertical seams, in which case the arc-welding process would have to be used.

Carbon electrodes are used for filling-in large cavities in cast iron, by melting into place a cast-iron rod of, say, $\frac{1}{2}$ inch diameter. A cast-iron metallic electrode of a diameter of about $\frac{1}{4}$ inch may also be used. Some makers of electric welding equipment recommend the use of soft iron electrodes on cast iron as well as on steel, and one concern uses a specially prepared soft iron electrode containing manganese.

Preparing Work for Welding. — The preparation of the work for welding depends upon the kind of work to be done, the thickness of the parts to be welded, and their shape. In Figs. 1, 2, and 3 are shown a number of examples of work to be welded, and in each case the method of preparing the work for welding,

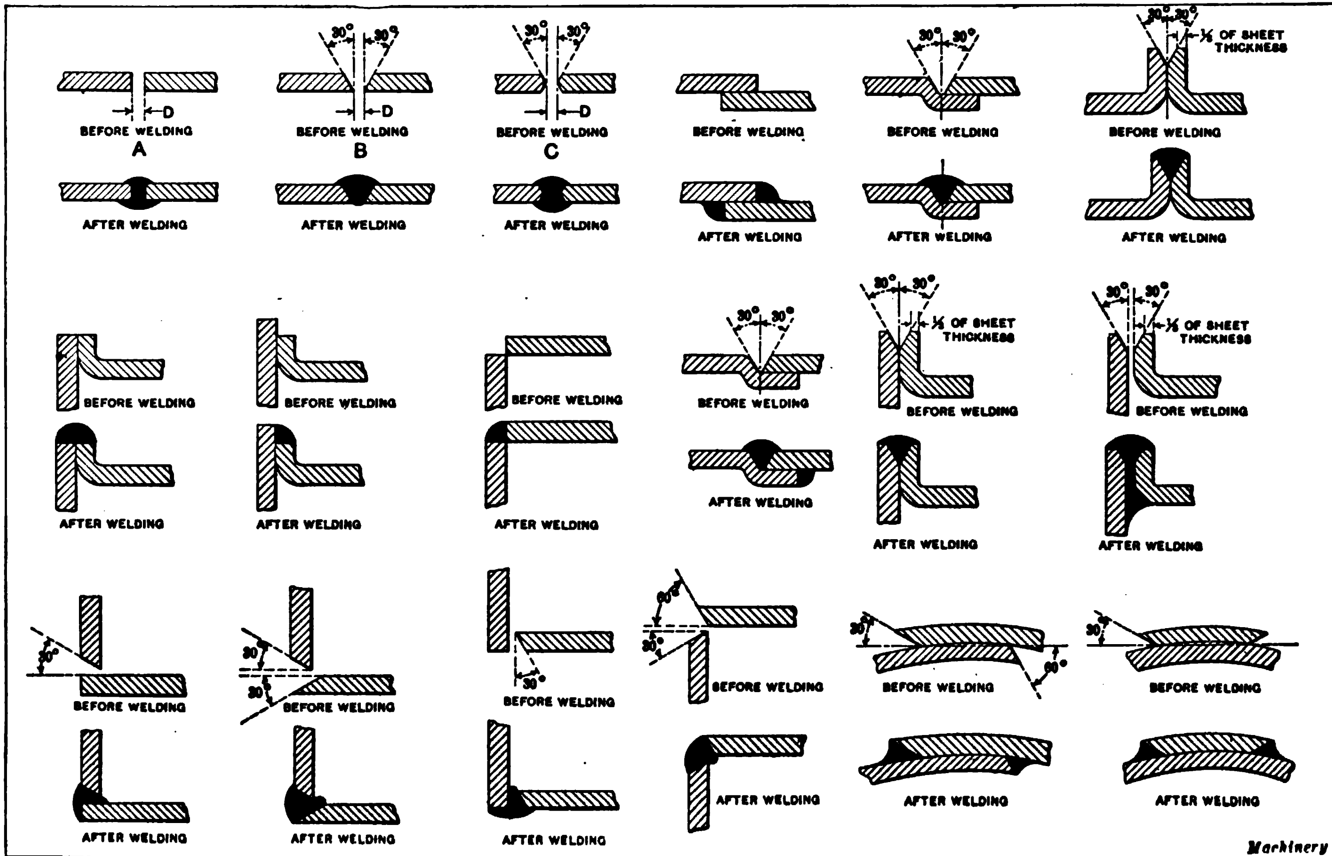


Fig. 1. Methods of preparing Sheet-metal Work for Welding

and the appearance of the weld after the work is completed, is shown. In Fig. 1 is indicated at A the method of preparing sheets less than $\frac{1}{4}$ inch in thickness. For sheets up to $\frac{1}{16}$ inch in thickness, space D should be $\frac{1}{32}$ inch. For sheets between $\frac{1}{16}$ and $\frac{1}{8}$ inch in thickness, it should be about $\frac{3}{32}$ inch; and for sheets from $\frac{1}{8}$ to $\frac{1}{4}$ inch in thickness, space D should be about $\frac{5}{32}$ inch. At B is shown the preparation of sheets from $\frac{1}{4}$ to $\frac{1}{2}$ inch in thickness, where space D should be $\frac{3}{32}$ inch. At C is shown plate above $\frac{1}{2}$ inch in thickness; here space D should be $\frac{5}{32}$ inch. A study of the various conditions illustrated in Figs. 1 2, and 3 will give a good idea both of the possibilities of electric welding and the method by which it is accomplished.

Preheating. — Cast and malleable iron can be successfully welded by the electric arc process, but it is generally necessary to preheat the castings, either by the use of the carbon electrode or by means of gas, coal or oil fires; the preheating is continued until the work is brought up to a red heat, and the heat is carried well back from the welding surfaces so as to avoid cooling strains and cracks when the metal cools after welding. The work must be kept hot during the time the weld is made, and means must be taken to have it cool down slowly after welding.

Equipment Required for Arc Welding. — The simplest possible outfit for arc welding would consist of any source of direct-current supply, an adjustable resistance for regulating the current and bringing the voltage down to that required in the welding circuit, and an electrode holder. The present arc-welding outfits, however, are made somewhat more elaborate in order to obtain greater economy. The current is usually furnished by a low-voltage generator which is driven by a motor or sometimes by other means, like a belt or chain drive. Generally, motor-generator sets or dynamotors are used for the power supply. The equipment further includes a switchboard having on it the starting apparatus for the motor end of the outfit, if motor-driven; the control and indicating apparatus for the generator, consisting of a field regulator, voltmeter, and ammeter; and a regulating apparatus for the arc circuit, consisting of a set of current-regulating switches with resistance, and usually

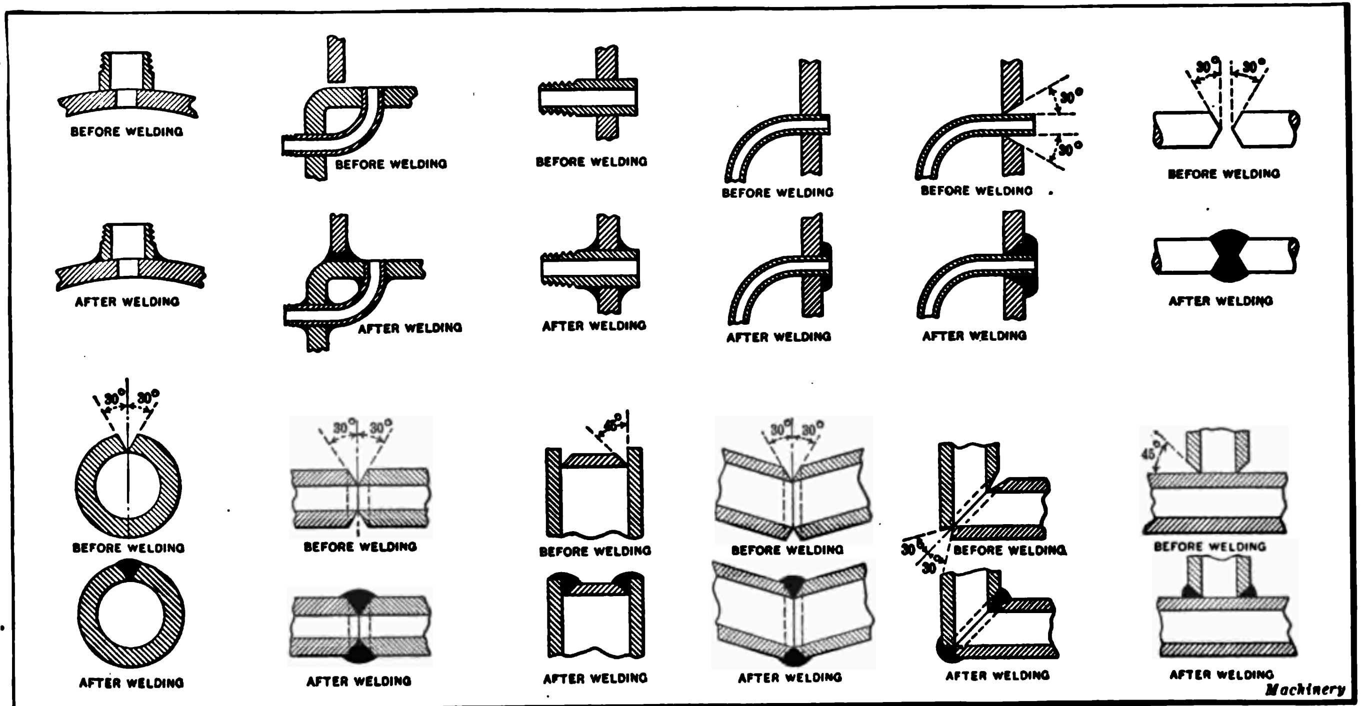


Fig. 2. Methods of preparing Piping and Tubular Work for Welding

some form of automatic switch or contactor. Where several welders use the same stationary outfit, there is, in addition, a control panel for each welding station or circuit. The operator's tools and equipment consist of electrode holders with cables for each welding station, and face shields or hoods for protection against the light and heat.

Motor-generator Sets. — As the alternating-current arc varies from a maximum to a minimum at each reversal of the current, it is not suitable for electric arc welding. The direct-current arc, on the other hand, is practically steady; so direct current is used; only a low voltage is required. The metallic arc requires from 15 to 25 volts, while the carbon arc requires from

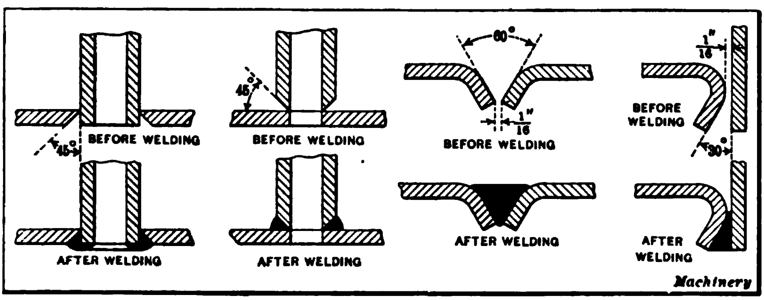


Fig. 3. Other Methods of preparing Piping for Welding

35 to 50 volts, according to the equipment used. Special welding equipment in the form of generators and control apparatus is used only in order to obtain current at the required voltage economically. As far as the welding is concerned, work can be done with the 250-volt direct current having the necessary resistance ballast; but it would be necessary to reduce the voltage from 250 volts to the low voltages required in the welding circuit. As this is done by inserting resistance in series with the arc to absorb the excess voltage, it is plainly an inefficient process, as the voltage absorbed by the rheostat is wasted. Assume that the supply circuit is 250 volts and that the arc requires 25 volts; then it is obvious that nine-tenths of the energy taken from the mains is wasted in the rheostat; and in

the extreme case of a supply circuit of 550 volts and a metallic arc using only 15 volts, the energy used would be so small a fraction of the energy taken from the line that practically all the energy of the supply circuit would be wasted.

In order to avoid these losses, therefore, the various manufacturers of electric welding apparatus have developed special low-voltage generators and methods of control that give the maximum of efficiency combined with flexibility and circuit protection. The generators are usually furnished as part of a motor-generator set, although they can be furnished for belt drive if desired. The motor-generator set, however, is the most desirable equipment for several reasons: It is a self-contained unit; it does not demand constant attention when running; the maintenance cost is low; and the welding circuits and the shop circuits are electrically independent, so that short-circuits in the welding circuit will not seriously interfere with the shop circuits. The voltage on the welding circuit can be regulated to suit the work being done by various methods of control, these methods differing according to the make of the equipment.

Types of Welding Equipment. — There are three types of equipment on the market, which may be described as the *constant-voltage*, the *variable-voltage*, and the *constant-current* types;

The *constant-voltage* type is a motor-generator set that takes power from the shop mains and delivers on the generator end a practically constant low voltage. A resistance ballast is used between the generator and the welding arc to determine the current and to limit the current at short-circuit. The power used in the resistance ballast is, of course, wasted. In stationary outfits, the low-voltage direct-current power is carried over the shop on heavy cable to the welding outlets.

The *variable-voltage* type is a motor-generator set in which the voltage supplied by the generator is variable, the generator delivering practically the voltage required by the arc.

The *constant-current* type is a motor-generator set that takes power from the shop mains and delivers on the generator end the current required for welding without the use of resistance ballast. The inherent characteristic of the generator is such

that the short-circuit current is limited without the use of resistance ballast. Inductive ballast is used to stabilize the arc. This type of equipment is usually furnished in the portable type, and the low-voltage distribution system is thus eliminated. The motor is fed directly from the shop lines. The constant-current type of welder has been developed to meet the demand for an outfit that will produce a welding current of constant value, regardless of the length of arc, and that can be

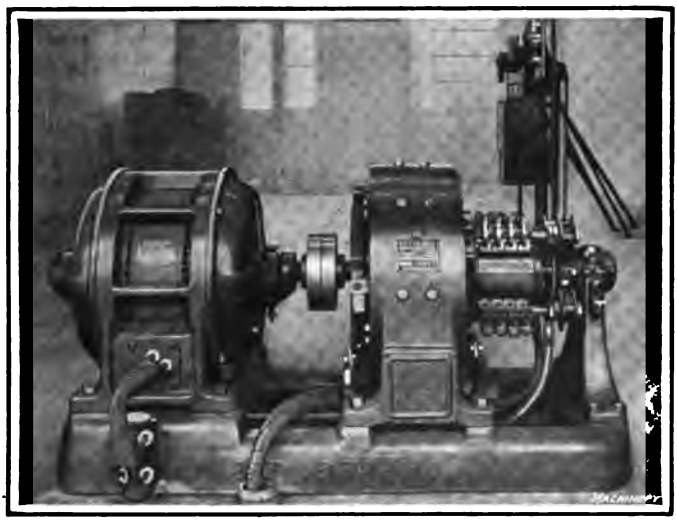


Fig. 4. General Electric Co. 500-ampere Electric Arc-welding Motor-generator Set

installed at any desired location in the shop. Machines of this type are so made that the voltage varies automatically as operating conditions change, thereby keeping the current at the predetermined amount. Provision is also made to adjust the current to different values to suit various classes of work, thereby making apparatus of this type suitable for all kinds of shops. These machines may be connected to the shop circuit like other motor-driven devices.

As examples of constant-voltage machines may be mentioned the generators of the Wilson Welder & Metals Co., which are wound for a voltage of 35 volts, and those of the General Electric

Co., which are wound for a voltage of from 60 to 75 volts; it is never necessary to have a generator of higher voltage than this for welding. The Lincoln Electric Co. supplies a variable-voltage equipment. At the instant of short-circuit, the voltage is very low — from two to three volts. When the operator is welding with the metallic arc the voltage across the arc is from twenty to twenty-five volts. Carbon electrode welding requires from thirty-five to fifty volts. When the machine is running, but the operator is not welding, the voltage may be from sixty

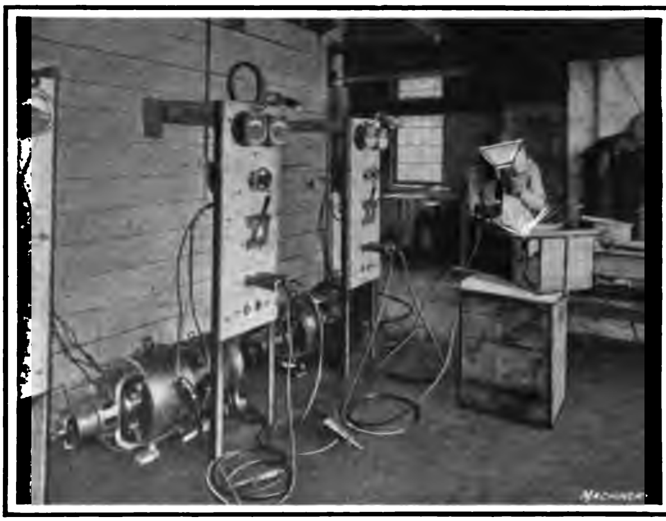


Fig. 5. Lincoln Electric Co. Equipment for Arc Welding

to eighty volts. The C & C Electric & Mfg. Co. makes a constant-current machine, working on the principles outlined.

Single-operator units of either type may be made portable. Large constant-voltage multiple-operator units must be located at definite points, although the welding panels may be made portable if the low-voltage distribution system is heavy enough to prevent interference between operators due to line-drop.

Dynamotors. — The C & C Electric & Mfg. Co. uses, in some cases, a dynamotor instead of a motor-generator set on

direct-current circuits. The dynamotor is a single machine, duplex-wound, combining the functions of both the motor and the generator. Dynamotors are somewhat lower in price than motor-generator sets, and are lighter and therefore desirable for portable outfits.

Examples of Welding Equipment. — Figs. 4, 5, 6, 7, and 8 show a number of welding outfits. That shown in Fig. 4 is a

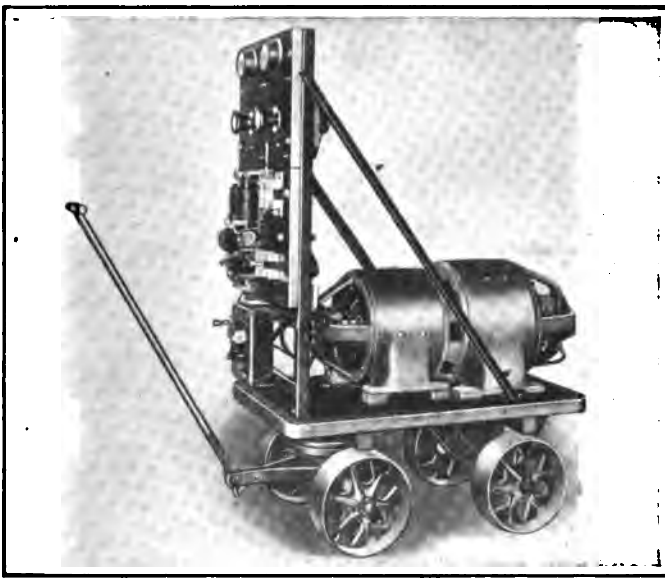


Fig. 6. C & C Electric & Mfg. Co. Portable 150-ampere Constant-current Welding Outfit

motor-generator set of 500 amperes capacity, the control equipment being shown in the background. This set is made by the General Electric Co. In Fig. 5 are shown two outfits made by the Lincoln Electric Co., together with the control switchboards. A welder is shown at work, this illustration giving a clear idea of the conditions under which the work is done. Two portable equipments are shown in Figs. 6 and 7. The equipment in Fig. 6 is the product of the C & C Electric & Mfg. Co., this particular outfit being wound for operation on a direct-current circuit; outfits wound for operation on alternating-current

circuits are also supplied. The equipment shown in Fig. 7 is made by the General Electric Co. These portable outfits consist of motor-generator sets with switchboards mounted directly on a truck. Fig. 8 shows a complete installation made by the Wilson Welder & Metals Co. It will be seen that there is one motor-generator set and six separate control panels, one for each welding circuit.

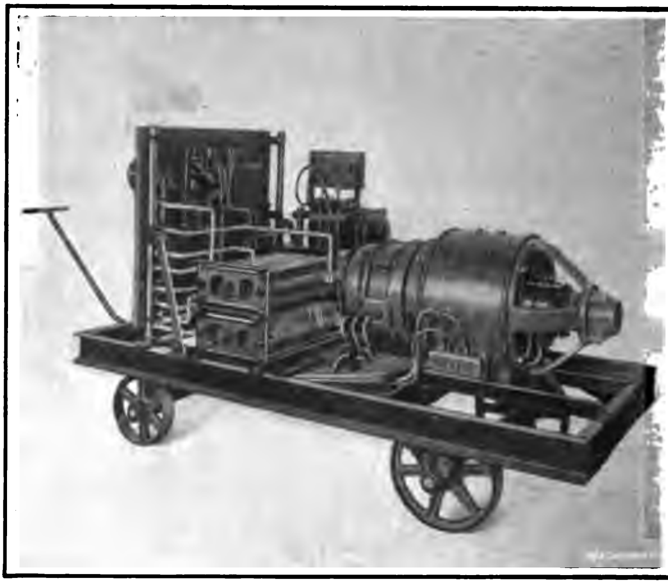


Fig. 7. General Electric Co. Portable 200-ampere Arc-welding Outfit

Switchboards. — It is generally preferable to have the apparatus for controlling the motor and generator on a separate panel from the welding control circuits, as this makes it possible to install the welding machine with its panel in a separate room, if desired, and to mount welding station panels near the work. In this way, the distribution circuit can be run from the control panel throughout the shop, and the welding panels can be tapped from this circuit the same as motors. Fig. 9 shows a diagram of connections for a C & C Electric & Mfg. Co.'s constant-voltage outfit. This gives automatic control of the weld-

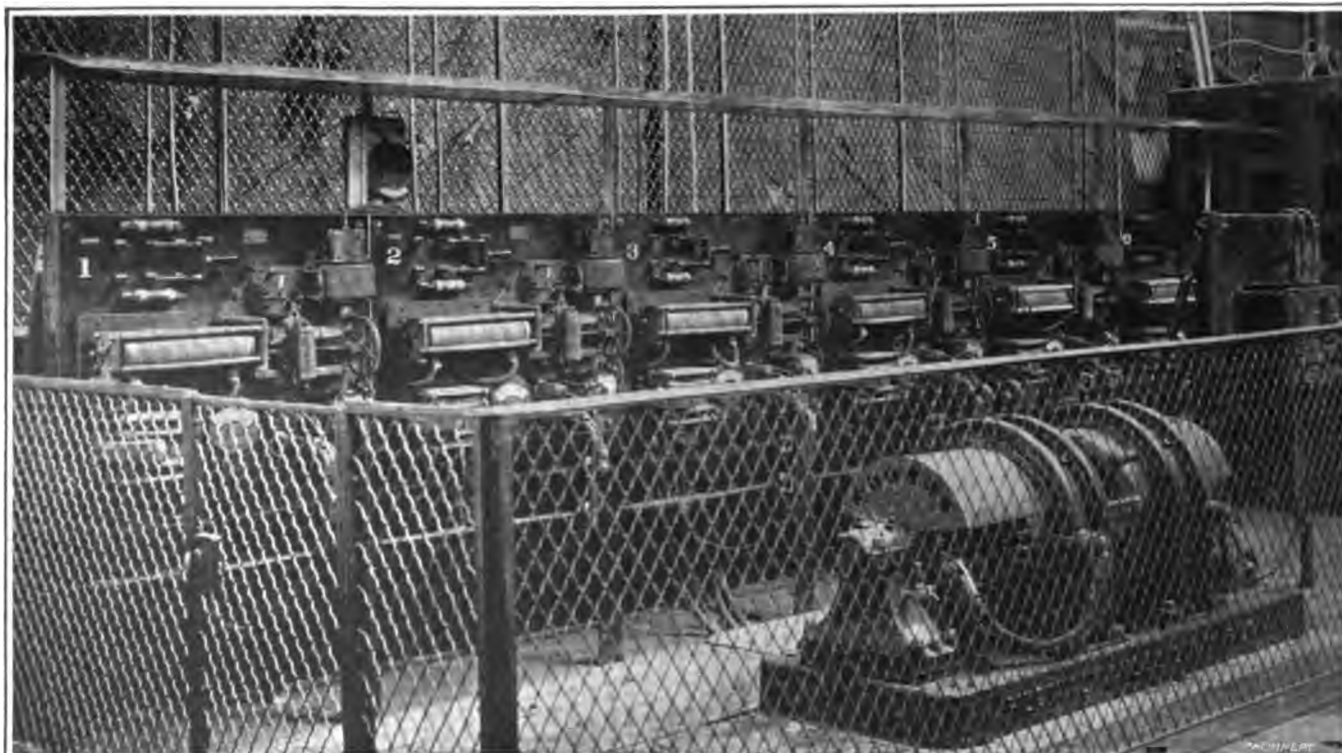


Fig. 8. Wilson Welder & Metals Co. Equipment for Electric Arc Welding — Six-panel Installation at American Locomotive Co., Dunkirk, N. Y.

ing current at all times. When the operator brings his electrode into contact with the work, the current is limited by all the resistance in the circuit, but when he draws his arc, the automatic contactor cuts out part of the resistance and allows the current to come up to the amount required for welding. Upon stopping work, the contactor drops back and all the devices are ready for further operation without attention. Should the operator attempt to use more current than has been determined to be proper for the job, a self-closing circuit-breaker acts immediately, interrupting the circuit, but permits resumption of

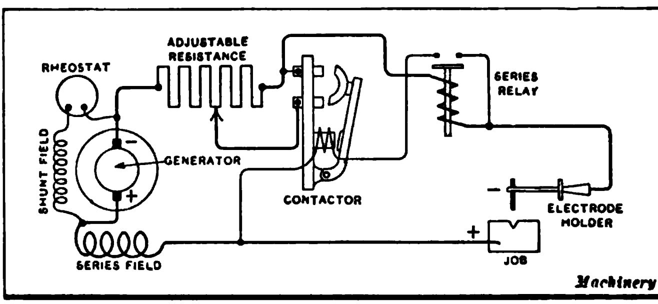


Fig. 9. Diagram of Connections for C & C Electric & Mfg. Co. Arc-welding Equipment

welding, without it being necessary to close the circuit-breaker manually.

The control of the welding circuit differs, as mentioned, according to the make of the welding outfit. In the General Electric Co.'s outfit, the control consists of a main generator panel and a separate panel for each operator. Double circuit panels are also provided, so that two operators can work from the same panel through separate equipments. If the circuits are duplicates, a set of switches can be provided for connecting the entire capacity of both circuits to one electrode. This is sometimes done for carbon electrode welding or cutting. A convenient type of switch is provided for adjusting the resistance in series with the arc and providing a number of steps in changing the current. Means are provided so that a large

number of operators can work from the same machine, since trouble on any one operating circuit is localized and does not affect any other. Circuit-breakers are mounted on the main generator panel, which will open the circuit in case of a short-circuit in the cables or in the event of an excessive load being thrown on the generator. Fig. 10 shows the connections of a G. E. arc-welding control panel for a generator and one welding

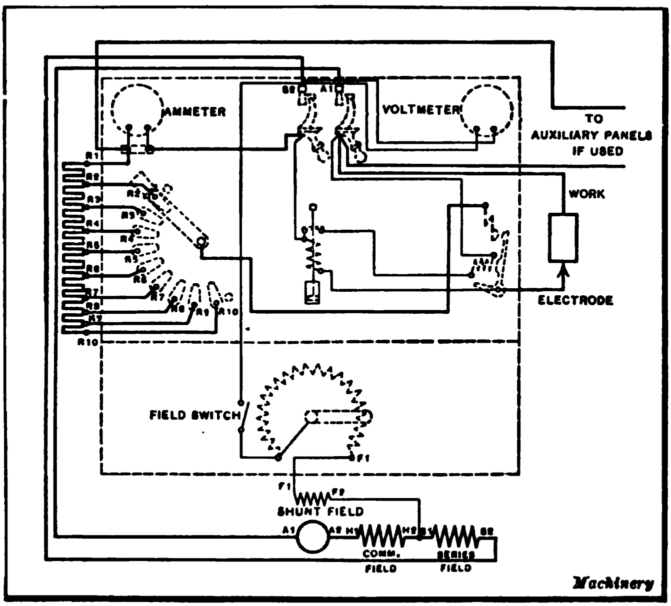


Fig. 10. Diagram of Connections for General Electric Co. Arc-welding Control Panel for Controlling Generator and One Welding Circuit

circuit, while Fig. 11 shows the connections of an auxiliary arc-welding control panel for one welding circuit.

In Fig. 12 is shown the constant current control panel for welding and cutting, provided for use in connection with the equipment made by the Wilson Welder & Metals Co. The more important parts on this control panel are as follows: 1, slate panel; 2, double-throw switch; 3, 300-ampere fuse; 4, switch receptacle; 5, carbon pile; 9, back-end disk cable; 10, front-end disk cable; 11, asbestos board; 12, choke coil; 13,

ammeter; 19, toggle circuit-breakers; 27, solenoid plunger; 28, solenoid casting; 29, solenoid; 30, dashpot; 31, piston-rod to dashpot; 32, $\frac{1}{10}$-horsepower motor; 33, welding circuit plug; 34, control circuit plug.

The general function of the control panel is to maintain a constant flow of current between the welding electrode and the

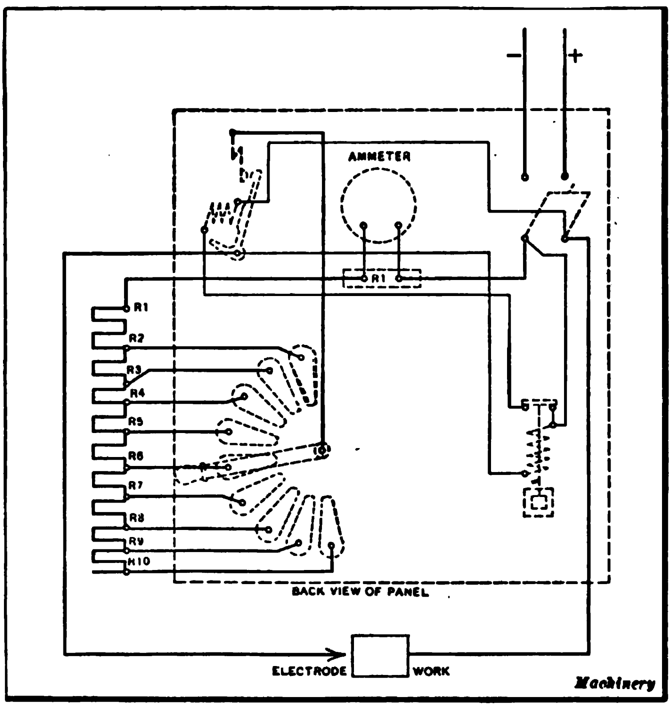


Fig. 11. Connections for General Electric Co. Arc-welding Auxiliary Control Panel for One Welding Circuit

material operated upon, regardless of variations in the resistance of the welding circuit due to varying lengths of arc or other causes. The current regulator consists of a carbon pile held under compression by one or more helical springs, the pull of which is opposed by a solenoid through which the current to be regulated is passed. A suitable air dashpot is connected to the solenoid plunger to prevent all "hunting" or chattering due to the

tendency of the plunger and connected parts to travel beyond the desired point. The pressure of the springs is transmitted to the carbon disks or plates through a lever, and the springs are mounted on a carriage in such a manner that the point at which they act upon the lever may be changed, thereby increasing or decreasing the leverage, as may be necessary. The position of the control solenoid in relation to the lever is fixed, and the movement of the spring carriage is produced by a small electric motor

Fig. 12. Wilson Welder & Metals Co. Constant-current Control Panel

so wired that it may be controlled by two push buttons located at the welding electrode holder or near enough to it so that the operator can use them without changing his position. The panel is also provided with a reactance coil of a size sufficient to assist the operator in maintaining an arc with a graphite pencil when the panel is used for cutting or burning away metal in preparing for the welding operation, or for other purposes. An ammeter is provided to indicate the amount of current used in the welding process, and a double-throw switch of 200 amperes

capacity is employed for changing from the welding to the cutting circuit.

A large foreign concern developed a machine some time ago fot utilizing the welding energy without losses. This machine generates energy at the required voltage directly, and always supplies current of the same strength, notwithstanding considerable resistance fluctuations in the welding circuit. At the same time, a perfectly steady arc is obtained. The heat flowing to the article welded is, therefore, quite constant, which is of importance for satisfactory welding. The peculiar property

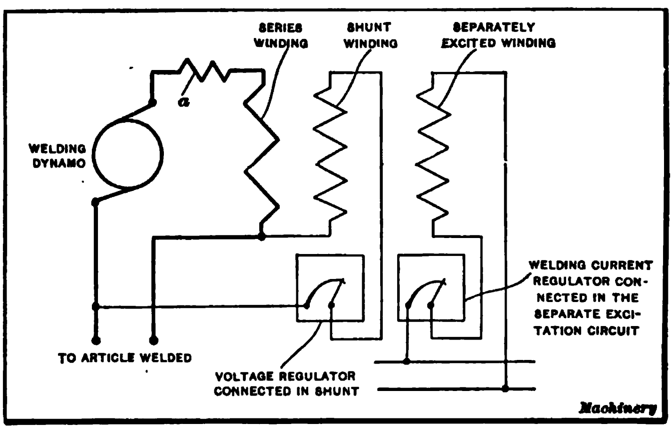


Fig. 13. Wiring Diagram of Kramer Electric Welding Machine

of this welding generator of giving a constant current with a variable resistance is obtained by means of a three-fold field excitation, as may be seen from the diagram of connections in Fig. 13. One field winding is a differentially connected series winding, the second is a shunt, and the third, a separately excited winding which receives current from a special circuit with a constant voltage. Any given welding current most suitable for the work can be obtained by adjusting the regulator for the separate excitation. The voltage of the machine may be altered by the regulator for the shunt excitation. Thus a finely graduated adjustment of the current and voltage may be obtained by

suitably arranging the two regulating resistances, so that the machine can be adapted within wide limits to the requirements for the welding work in hand. Fig. 14 illustrates the value of the current for the machine adjusted for a welding current of 150 amperes. It clearly shows that the welding current remains constant even when the arc resistance varies from zero (*i.e.*, short-circuit) to 0.5 ohm. Only after attaining a still higher resistance does the current begin to fall gradually.

Flexibility of the System. — Welding can be done at any distance from the outfit, the only limit being the allowable voltage

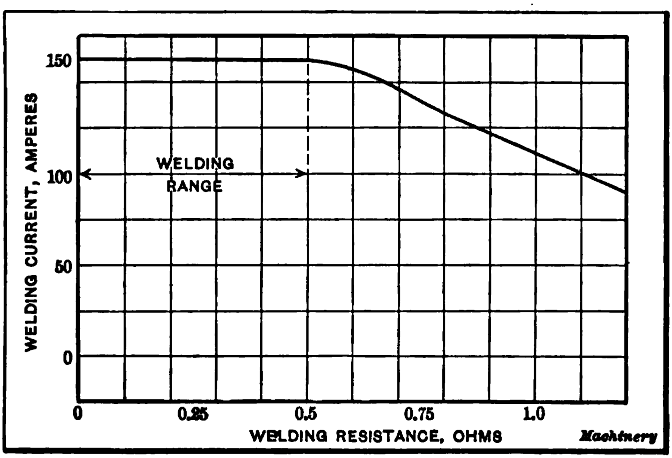


Fig. 14. Diagram of Current in Relation to Resistance

drop in the lines to the work and the electrode. This, in turn, can be regulated to a certain extent by increasing the size of the cable as the distance increases. Beyond 500 or 600 feet, however, this method is hardly practicable for any work other than that which can be done with the metallic electrode, as the size of the cable required for carbon arc work with its large currents would increase to such an extent that its cost would be prohibitive and the handling of the cable exceedingly difficult. To meet conditions of this character, a complete portable outfit consisting of generating and regulating apparatus, mounted on a truck that can be moved from place to place, is most appropriate.

For land use, the generator end of such an outfit is usually motor-driven, while, for marine work, steam-driven outfits mounted on barges afford the most convenient arrangement.

It is not necessary that the operation of welding always take place in a downward direction. While work with the carbon arc has to be done in this position, due to the flowing of the metal into the weld, the metallic arc can be used as readily on vertical or overhead welds as on downward ones, the only difference being in the rate at which the metal is applied. Owing to the fact that, in any position other than downward, the metal is applied against the force of gravity, its rate of flow from the electrode is necessarily slower. This feature of being able to weld with the work in any position occasions a great saving in the amount of handling which would have to be done were it necessary that all welding take place in a downward direction. The arc process of welding is thus seen to be exceedingly flexible in its application, covering work of practically all classes and degrees of accessibility, and this feature greatly facilitates the operation of welding. Handling of the work is reduced to a minimum, and welds are made with an ease and rapidity not approached by any other method.

Operation of a Welding Outfit. — As mentioned, the control of the General Electric Co.'s constant-voltage arc-welding outfit consists of a main generator panel and a separate panel for each operator. The dial switch on the auxiliary panel controls the amount of resistance in series with the arc and, therefore, controls the current used. This is regulated as required by the work to be done. The automatic control equipment gives thorough protection to the generator without affecting other operators whose welding circuits may be connected to the same generator. This equipment consists of a protective relay controlling a shunt contactor in the welding circuit. The relay is provided with an oil dashpot and, therefore, will not operate on momentary fluctuations of current. Before starting the arc, the operator sets the dial switch for the amount of current required for the work, so that, on starting, the circuits are in the normal running position. Thus, there is no necessity for having

any relays or switches open or closed, or in any way disturbing the electrical circuit in order to weld.

However, if the operator leaves the electrode in contact with the work too long, or takes too much current after having drawn the arc, the protective relay opens the contactor exciting coil, which, in turn, opens the welding circuit. In order to resume operations, it is necessary only for the operator to lift the electrode, breaking the circuit, whereupon the relay drops out, closing the contactor and restoring the circuits to the normal operating condition. This system gives complete protection to the generator and assists the operator by making it unnecessary for him to leave his work to close the circuit-breaker, or to lose time in any other way. Other operators, whose welding circuits are connected to the same generator, are not involved in any way, since this protection affects only the circuit in trouble. In case of an extremely heavy load or a severe short-circuit in the cables, the circuit-breakers on the main panel will open the generator circuit.

Aside from the use of judgment in the application of the electric arc-welding process, there are three rules that the operator must observe in order to obtain the best results in welding: (1) Hold a short arc. (2) Use a low current. (3) Always work on clean metal.

Electrode Holders and Cable. — The electrode holders are generally designed in a simple manner mechanically, and provided with means for holding the electrode firmly. Generally a new electrode is held in the holder about half way down on the electrode, and moved out as required. The holder is insulated where the hand grips it, and provides for the connection from the source of current supply to the electrode. In the design of electrodes, small, flimsy, or light projecting parts should be avoided, as they are likely to be broken off or bent. It is highly important in the design of a holder to make it fool-proof to the extent that it is practically impossible to burn or damage it by accidental contact, so that it would become inoperative. Fig. 15 shows a recent design of electrode holder.

The cable leading to the electrode holder should be exceedingly

flexible, so that the operator has absolute control of the holder and the arc. The cable generally specified is extra-flexible, stranded, dynamo cable, with varnished cambric insulation, covered with weather-proof braid. The following sizes of cable have been found suitable: Up to 200 amperes, size of cable, 225/24 of 90,000 circular mils; from 200 to 500 amperes, size of cable, 375/24 of 150,000 circular mils; from 500 to 1000 amperes, size of cable, 650/24 of 260,000 circular mils. The figures indicating the size of the cable designate the stranding; for example, a 225/24 cable is one formed by stranding together 225 wires,

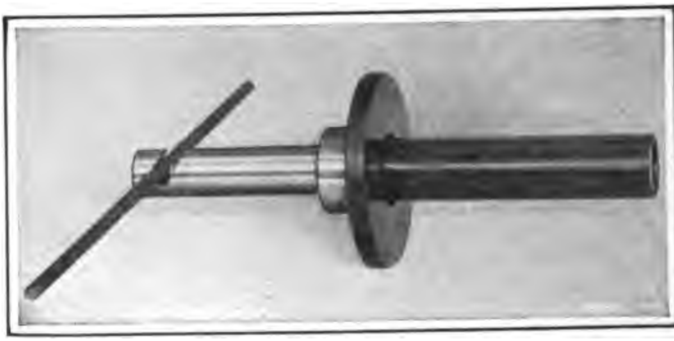


Fig. 15. General Electric Co. Metallic Electrode Holder for Electric Arc Welding

each of which is No. 24 Brown & Sharpe or American standard wire gage.

Striking Arc and Handling Electrodes. — The arc is established by momentarily touching the electrode to the work and then withdrawing it a short distance. Practice is necessary in order to manipulate the electrode so as to maintain an approximately constant length of arc while welding. Skill in this respect is of importance to a welder, as variations in the length of the arc, in strictly constant-voltage machines, cause corresponding variations in the amount of current, which, in turn, causes variations in heat and thus in the quality and uniformity of the metal in the weld. As the carbon arc is considerably longer than the metallic arc, it is more stable and less likely to break. The

metallic arc is very short, being only from $\frac{1}{8}$ to $\frac{1}{4}$ inch long. After the arc is established, it can be moved about along the work by merely moving the electrode. The carbon electrode is frequently used for preheating such work as castings, the preheating being extended a distance from the weld by keeping the electrode moving rapidly enough so as not to melt the work. In welding with the carbon electrode, the operator holds the electrode holder in one hand and feeds the rod of filling material into the arc with the other. The filling material is melted into the weld and mixes with the molten material of the work, forming a homogeneous mass of metal in the weld. As mentioned, the carbon arc is largely used for building up worn surfaces, owing to the rapidity with which a large amount of metal can be built up; but there are certain advantages in using the metal electrode for some classes of work, as will be mentioned in connection with the application of electric arc welding to railroad shops.

When heavy plate is welded with more than one layer of metal in the joint, the operator should brush off the layer of oxide from the metal with a stiff brush, commonly known as a "casting brush" or a "painter's wire brush." This is done in order that the metal throughout the weld may be free from slag and oxide. If this is not done, there will not be a proper adherence between the two layers of metal, which may result in a leaky or spongy weld. In work on tanks that will contain liquids under pressure, and where a homogeneous weld free from blow-holes is necessary, a short arc and slow speed in the work, with a comparatively low current, the metallic electrode being used, will insure the best results.

Protection of Operator. — Owing to the intensity of the light and heat rays from the arc, careful protection of the operator's hands, face, and eyes is extremely important, especially in the case of the carbon arc, where the volume of light and heat is very great. Heavy gloves serve to protect the hands, while for the face some form of shield held in the hand or supported from the head is used. This is provided with an opening filled with several thicknesses of ruby or blue glass, which affords protec-

tion to the eyes and still permits the welding operation to be closely followed. A satisfactory shield for building-up operations can be made of a soft pine board or sheet metal with a small slot in it for the protective glass. Firebox work requires a head shield which should be made of hard fiber. The color combination in the protective glass is of importance. Two red glasses and one blue glass or two reds and a green give good results. Special glass put out under various trade names is also satisfactory. As a rule, the operator tries several combinations

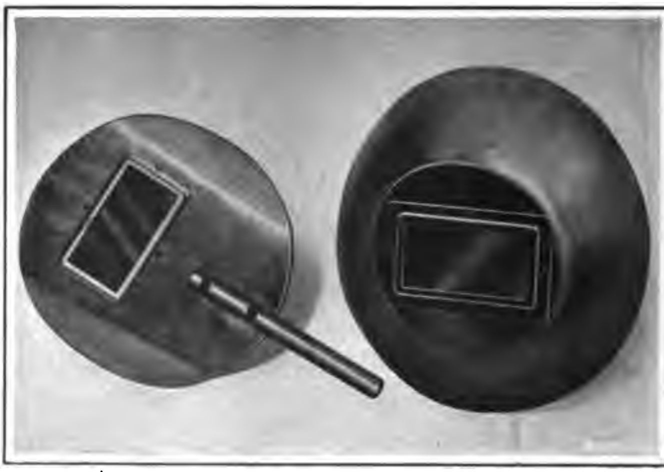


Fig. 16. Front View of Two Types of Welding Shields

until he finds one that seems to suit his eyes best. While the operator is working outside the firebox, the other men should be protected from the light of the arc by screens. Portable screens should be used where work is done on the floor. Where there is a regular welding bench, permanent curtains should be provided. The screens should always be designed to protect the crane operators from the flash of the arc. Figs. 16 and 17 show front and rear views, respectively, of two types of face shields used by the General Electric Co. A number of the illustrations in Chapter VIII, showing operators at work, also indicate the different types of shields that are employed.

Capacity of Outfits. — The C & C Electric & Mfg. Co., Garwood, N. J., builds constant-voltage equipments in sizes of from 300 to 1500 amperes, and constant-current machines from 25 to 600 amperes. The company recommends the constant-current type on the score of economy and higher efficiency in the welds. For large castings and forgings and, in general, for all sections of from 1 to 6 inches in thickness, machines of from 400 to 600 amperes capacity are required. Large shafting or parts of very

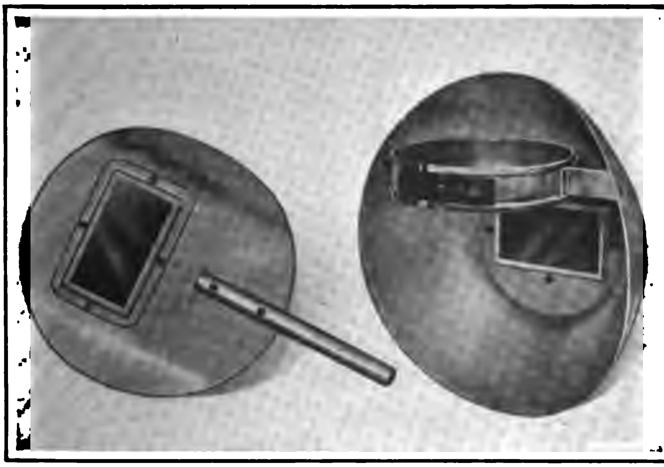


Fig. 17. Rear View of Welding Shields shown in Fig. 16

heavy section require machines of from 600 to 900 amperes. In steel foundries, for example, machines of from 750 to 900 amperes are used, providing there is not much cutting or burning to be done. In the latter case, when heavy risers are removed and similar work is done by the arc, a capacity of from 800 to 1000 amperes will be required. The welding of sheet metal and steel plate does not require more than a maximum of 200 amperes, according to the thickness of stock used.

The General Electric Co., Schenectady, N. Y., builds outfits in capacities from 200 to 1250 amperes for stationary use, and from 200 to 400 amperes for portable use. For metallic elec-

trode welding, machines having 200 amperes capacity are sufficient for one operator, and where a number of operators are working from one set, under average conditions, from 125 to 150 amperes per operator should be provided. For light welding by the carbon electrode, about 200 amperes is sufficient; for medium welding, up to 400 amperes; and for heavy welding, up to 500 amperes. For cutting or melting, from 300 to 1000 amperes is needed, according to the thickness of the metal.

Cost of Electric Arc Welding. — It is difficult to give accurate figures covering the cost of welding, whether the work be done by the electric arc or by some other method. The work varies to such an extent that it would be impossible to give the exact cost of any particular job in advance. Furthermore, the cost of the current, the wages paid, and the skill of the welder will vary. All these factors, of course, have a direct influence on the cost of making the weld. Of the three factors mentioned, the first — the cost of the current — varies between the widest limits, as wages are fairly well standardized for this work, and the time required for making the weld should not vary much where good welders are employed. The costs in the following paragraphs are figured on the basis of labor at 30 cents per hour; at the present time the cost of labor will be higher than that, plants employing arc welding as a regular manufacturing process paying good welders as much as 50 cents an hour.

The C & C Electric & Mfg. Co. furnishes the following data showing the time required for, and the cost of, a number of actual jobs done with the company's 70-volt constant-voltage arc-welding outfit, labor being paid at 30 cents per hour and current figured at 2 cents per kilowatt hour: Forged steel locomotive frame broken in two places: time, 20 hours; cost, $18.28. Welding 67 cracks in old firebox (saving over $1000): time, two weeks; cost, $52.60. Steel shaft, 2 inches in diameter: time, 1 hour; cost, 60 cents. Cutting off riser of steel casting 4 by 4 inches: time, 4 minutes; cost, 5 cents. Building up 2-inch armature shafts worn in journals: time, 3 hours; cost, $1.80. These figures, of course, include only labor and current required, and not overhead costs. As regards the comparative

cost of electric arc welding and oxy-acetylene welding, it is generally conceded that oxy-acetylene welding is cheaper for the welding of steel plate thinner than $\frac{1}{8}$ inch, but that arc welding is cheaper when the plate is thicker than $\frac{1}{8}$ inch, and the cost is materially reduced by arc welding for plates as thick as $\frac{1}{2}$ or $\frac{3}{4}$ inch.

The Lincoln Electric Co., Cleveland, Ohio, in comparing the cost of welding with that of riveting, estimates that the ratio of the cost of labor for arc welding to the cost of labor for riveting is as 6.5 to 10. The cost of power required for arc welding as compared with that of riveting is as 1 to 2. The investment required by the arc-welding apparatus is about 25 per cent higher than the cost of riveting machinery but this is easily offset by the lower operating and power cost.

The following figures based on labor at 30 cents per hour and current at 2 cents per kilowatt were published some years ago in MACHINERY: A broken shaft 2 inches in diameter was welded and ready for refinishing in one hour; the current used was 350 amperes and the total cost, 79 cents. A crack in the back sheet of a locomotive boiler 12 inches long was welded in nine hours, the current used was 175 amperes and the total cost, $4.90. The risers on a steel casting, 4 by 4 inches in size, were cut off in four minutes; the current used was 350 amperes and the total cost, 5.2 cents. A cast-steel tender frame broken in three places was welded in twenty-seven hours; the current used was 300 amperes and the total cost, $19.44. The journals of a worn 2-inch armature shaft were built up in three hours; the current used was 165 amperes and the cost, $1.59. As an example of straight welding on sheet-metal work, seams on $\frac{1}{8}$-inch steel can be welded at the rate of from 15 to 16 feet per hour, and on $\frac{1}{4}$-inch steel, at the rate of from 12 to 13 feet per hour.

Metallurgy of Electric Arc Welding. — As stated in a report submitted to the Association of Railway Electrical Engineers, the metal electrode arc-welding process, "reduced to its simplest terms, simply involves the melting of steel wire and allowing it to flow while molten onto another piece of steel which has been

melted over a local area. Three important changes take place in the metal during this process: 1. The effect of mechanical treatment is entirely eliminated over the area heated to a plastic or molten state, and the metal thus affected becomes cast steel. 2. Unless the molten metal is protected by a slag covering, it is oxidized to a certain extent by the oxygen present in the atmosphere. This oxidation tends to make the metal cold-short. 3. A large percentage of the impurities (carbon, manganese, nickel vanadium, chrominum, etc.), which may be present in the steel effected by the welding process before the operation, is vaporized or oxidized and has disappeared after the operation.

"The net result is that, in bare wire welding, the metal obtained in the weld may be as high in tensile strength as the metal in the original piece being welded. It will be rather low in ductility, but will be soft if the metal before the operation was not over 0.35 per cent in carbon content.

"No method has been demonstrated up to the present time of giving the cast steel in the weld the same characteristics to the same degree as those found in flange steel. The same tensile strength and equal softness can be obtained; but with the present development of the art of welding with the electric arc, equal ductility has not been produced. The cast steel in the weld may have practically the same characteristics as the cast steel used in locomotive construction as far as tensile strength, ductility, and softness are concerned. In spite of the comparatively low degree of ductility of the metal obtained in the weld, the process is entirely practical as a means of welding both cast steel and boiler plate, owing to the fact that the welded area may be reinforced where great resistance to fracture must be produced. The net result of this practice is to stiffen the welded section to such an extent that, under severe stress, the original and unwelded section will fail before the metal in the weld is strained to the point of rupture."

Strength of Electric Welds. — By careful selection of metal electrodes and skill in making the weld, it has been found possible to make welds having a tensile strength of from 95 to 97 per cent

of the strength of the original section, but for average conditions it may be assumed that the electric arc weld has a strength of from 80 to 90 per cent of that of the metal. It is possible, however, to reinforce the welded section in many instances by building up at the point of the weld, thereby making the cross-section of the weld greater than the metal itself. Electrically welded joints are stronger than riveted joints, and when the joint is hammered while hot the ductility of the metal will be increased.

Foster superheater flues made by the Power Specialty Co., and welded by the C & C Electric & Mfg. Co.'s outfit, were tested at Columbia University with a hydraulic pressure of 5500 pounds per square inch without leakage or fracture. A receiver made of $\frac{1}{2}$-inch steel plate with $\frac{5}{8}$-inch flat heads, all joints being welded, was tested with a pressure of 3600 pounds per square inch, without leakage or fracture.

In order to test the relative values of different kinds of welded joints, steel plate $\frac{3}{8}$ inch thick was welded. The original piece was assumed to have a strength of 100 per cent; the electric arc-welded lap-joint was found to have a strength of 93.5 per cent, and the electric arc-welded butt-joint, a strength of 81.5 per cent. A riveted lap-joint, single riveting, had a strength of only about 60 per cent. With heavy sections like boiler plates, the strength after welding, given in the case of butt-joints, if properly made should average about 90 per cent of the original strength of the plate. The elongation in the welded material is less than in the original plate, because it is not as tenacious, but the ductility can be improved by hammering the weld while still hot, and this is frequently done on heavy sections.

In one case, 200 steel specimens welded together by the arc-welding method were tested to determine the strength of the weld. The results of these tests indicated that the elastic limit of the original specimens was 46,900 pounds per square inch and of the welded specimens, 45,600 pounds per square inch. The ultimate strength of the original specimens was 61,500 pounds per square inch, and that of the welded specimens, 48,600 pounds

per square inch. These specimens were steel bars, $1\frac{1}{2}$ by $\frac{3}{8}$ inch, gripped 18 inches apart. The bars tested had been beveled on both sides and welded.

Figs. 18 and 19 show two interesting examples of electric welding, the welds having been tested for strength. Fig. 18 shows a six-inch standard wrought-iron pipe on which one cap at the end and one seam at the center were welded by the electric arc. A cap was then screwed onto the other end and the pipe subjected to a test pressure of 1000 pounds per square inch, which it withstood successfully. Fig. 19 shows an 8-inch

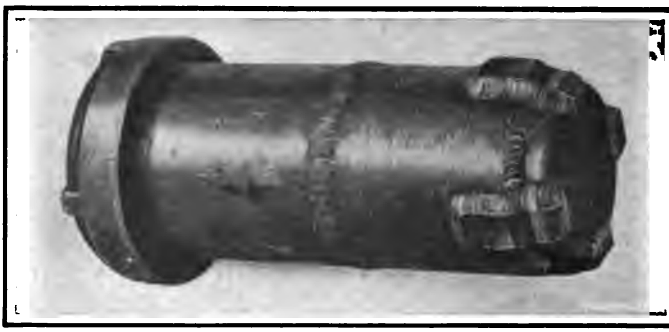


Fig. 18. Six-inch Arc-welded Wrought-iron Pipe tested at a Pressure of 1000 Pounds per Square Inch

standard wrought-iron pipe welded in the same manner. Here, when subjected to an internal pressure of 800 pounds per square inch, the cap screwed onto one end of the pipe broke as indicated, but the welds did not fracture. These tests were made by the General Electric Co. Fig. 20 shows the electric welding of a steam plate for a hydraulic press. Two $\frac{3}{4}$-inch steel plates are held with keys and the joint between them is welded. The size of the plate is 40 by 40 inches and the steam pressure is 150 pounds per square inch. Of course, the keys in this case take the main strain, as far as holding the parts together is concerned, but the welding provides for a steam-tight joint at the pressure mentioned.

Quality of Weld. — With regard to the nature of the weld, the Lincoln Electric Co. calls attention to a fact that should not be

overlooked, namely, that the new metal in a weld is simply metal that has been melted and cooled again, and it partakes of the properties of cast metal rather than of rolled or wrought metal. For instance, in welding two pieces of boiler plate, the weld will have nearly as great a tensile strength as the original plate, but the weld is really cast steel, and therefore has not the ductility that the rolled steel plate possesses. By the use of special welding material, however, the Wilson Welder & Metals Co. has produced welds that will bend, when tested, almost the same as wrought iron or mild steel; this has also been the experience of

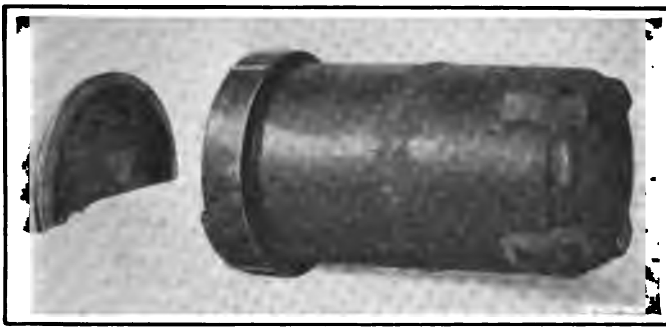


Fig. 19. Eight-inch Arc-welded Wrought-iron Pipe tested at a Pressure of 800 Pounds per Square Inch, which was withstood by the Welds but not by the Cap

the C & C Electric & Mfg. Co., when using its constant-current machine and regular Swedish iron electrodes, as advocated by this company.

It has often been stated that the welds are too hard to be machined, but this is a mistaken idea. A properly made electric arc weld can be machined as readily as a steel casting or a piece of flange steel. This characteristic of the weld has made it possible to employ the arc-welding process not only for repair work, but also in regular manufacturing practice.

Conclusion. — From a consideration of the foregoing, the principal reasons for the success of electric arc welding — both as a repair means and as a manufacturing means — will be readily appreciated. They may be briefly summarized as follows: The

adaptability of the process to work of an exceedingly varied character, practically all cases in which iron or steel have to be united being covered by the carbon and metallic arc methods. To this may be added the opposite case, or that of cutting, where the arc is equally effective even if not as economical as the gas cutting processes. The fact that vertical or overhead welds can be made as readily as downward welds greatly increases the availability of the process for certain classes of work, and reduces to a minimum the labor which would otherwise be required for handling. The low cost of welding by this process, as seen when comparison is made with like results obtained by other methods, is a decided argument in its favor. In many cases of repair work,

Fig. 20. Steam Plate for Hydraulic Press welded to withstand a Steam Pressure of 150 Pounds per Square Inch

where the electric process is not available, the entire replacing of the broken or worn part would be necessary at a cost many times greater than required for welding. The application of the electric arc-welding process to the repair work in locomotive shops and engine houses, for example, is a profitable proposition for the railroad.

Any number of operators may work from the same outfit up to its capacity. They may be doing different classes of work, and at any distance from the outfit up to limits fixed by the allowable voltage drop in the lines. This feature is particularly effective in those cases where the job is large enough to permit of several operators working at one time. The low voltage used for welding precludes all chance of accident to the operator from contact with current-carrying parts of the apparatus. Welds made by the electric arc possess a degree of strength only slightly below that of the original section, and by reinforcing, the strength

can be increased to any desired amount. They present a neat and finished appearance, are homogeneous in structure, and may be easily machined.

In view of these advantages, it is readily understood why electric arc welding has made such rapid strides during the last few years. Several manufacturers of electrical machinery and apparatus have taken up the making of welding outfits, and some concerns are devoting themselves exclusively to this one branch of electrical machinery. The art of electric arc welding is becoming better understood, and in the future the process will, no doubt, become of even greater importance than at present.

CHAPTER VIII

APPLICATIONS OF ELECTRIC ARC WELDING

Electric welding is used in the machine industries both in repair and manufacturing work. It provides a rapid and simple means for quickly repairing broken castings, so that machinery that has broken down may be rapidly put back into operation.

Fig. 1. Broken Lathe Steadyrest

By the aid of the electric arc, machines with broken parts may be put in running condition in a few hours, where it might require days or weeks if the parts had to be cast and machined. Fig. 1 shows a broken lathe steadyrest, and Fig. 2 shows the same steadyrest after being welded. Fig. 3 indicates the value of

electric arc welding in cases of a serious breakdown. Here the arm of a radial drilling machine is broken at the post. In this case, the making of a new casting and the machining of the arm would have required considerable time. Fig. 4 shows the break welded and the drill ready for operation. In Fig. 5 is shown another large welding job in a casting that would be costly to make in the foundry and equally costly to machine. This is a bearing cap for a 500-ton punch press. The carbon arc was used

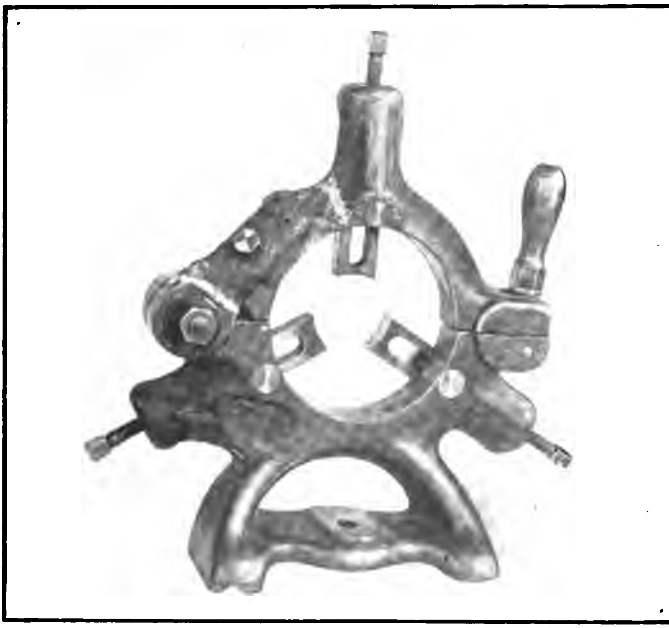


Fig. 2. Lathe Steadyrest shown in Fig. 1 repaired

in making this repair. This work was done at the Pressed Steel Products Co.'s plant with a C & C Electric & Mfg. Co.'s equipment.

Broken gears can be successfully welded with the electric arc, both in the case of broken arms and rims and broken teeth. In the latter case, of course, the tooth that has been built up must be machined. Fig. 6 shows a large spur gear with one arm broken in two places and the rim fractured in three places, which

has been successfully repaired by a General Electric Co.'s equipment, while Fig. 7 shows an example of repairing the teeth in a bevel pinion with a Lincoln Electric Co.'s equipment. This illustration also shows a good form of face and head protector.

Another important field for electric arc welding is that of building up worn parts and filling in holes or defects in castings that

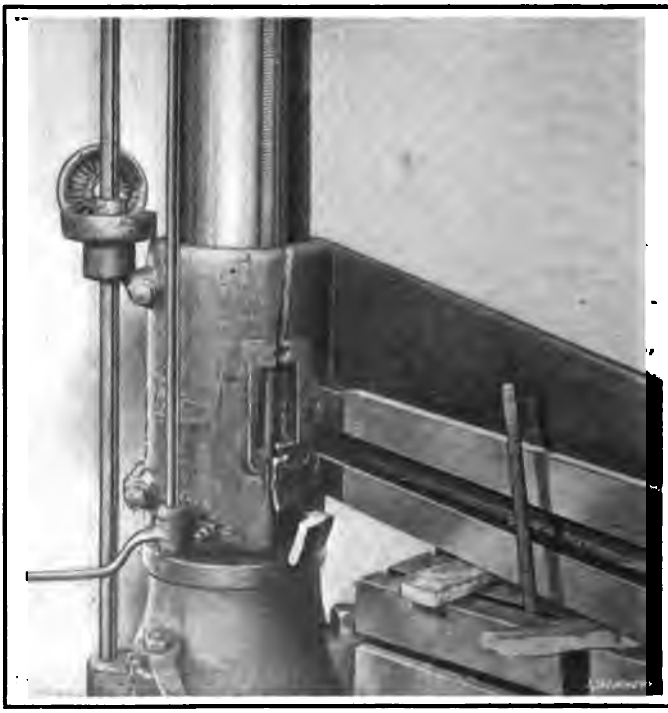


Fig. 3. Broken Arm of Radial Drilling Machine

would otherwise be scrapped. In Fig. 8 is shown an example of a casting with a large blow-hole that is being filled in and built up by using the carbon arc and a metal filling rod, so as to save the casting. In Fig. 9 is shown the reclamation of worn freight-car knuckles by building up the worn parts on the knuckles so that they can be used again. On one railroad line alone it is stated that the saving in one year in the reclaiming of freight-car knuckles that would otherwise be scrapped amounts to more than

$20,000. This work is done with the Wilson Welder & Metals Co.'s equipment.

An interesting application of the electric arc is in building up flat spots on locomotive and car wheels. In Fig. 10 is shown an example of how the welding is done on a locomotive driving wheel in place on the engine. The cost of building up a flat spot

Fig. 4. Arm of Radial Drilling Machine repaired

amounts to about $2, and the saving is estimated at about $200. In Fig. 11 is shown a locomotive trailer wheel with a flat spot, the wheel having been prepared for welding by the electric arc. Fig. 12 shows the same wheel with the flat spot built up by welding.

While the illustrations shown are of a varied character and show work done with both the carbon and metallic arcs — with a considerable range of current — they do not in any way repre-

sent the complete possibilities of the process of arc welding and cutting. Fig. 14 shows an example of tank welding, in which the head, flange, and branches of a tank 42 inches in diameter were welded with the metallic arc. The current required was approximately 165 amperes at 70 volts. The finished appearance of the welds and the necessity for little subsequent trimming will be evident from this illustration. Figs. 13 and 15 show a fractured section of a locomotive frame before and after welding.

Fig. 5. Bearing Cap for 500-ton Punch Press repaired with Carbon Arc

In repairing a break of this nature, the metal is cut away along the line of fracture, forming a V-shaped opening. This is filled with the repairing metal. The current required for work of this kind will vary from 500 to 600 amperes. It will be noted that the section has been reinforced where the metal was added.

Figs. 16 and 17 show the repair of a fractured mud-ring of a locomotive firebox. It will be seen that part of the throat sheet has been cut away in Fig. 16 in order to give access to the mud-ring. The fractures in the corners are first opened up with the carbon arc preparatory to welding, and after the weld is completed the sections of the throat sheet are replaced and welded

as shown in Fig. 17. In this illustration, it will be noticed that the weld on the right-hand side has been dressed, while that on the left has not. The latter shows the appearance of the weld immediately after making a repair with the metallic arc. Figs. 18 and 19 show a broken casting of a wood planer before and

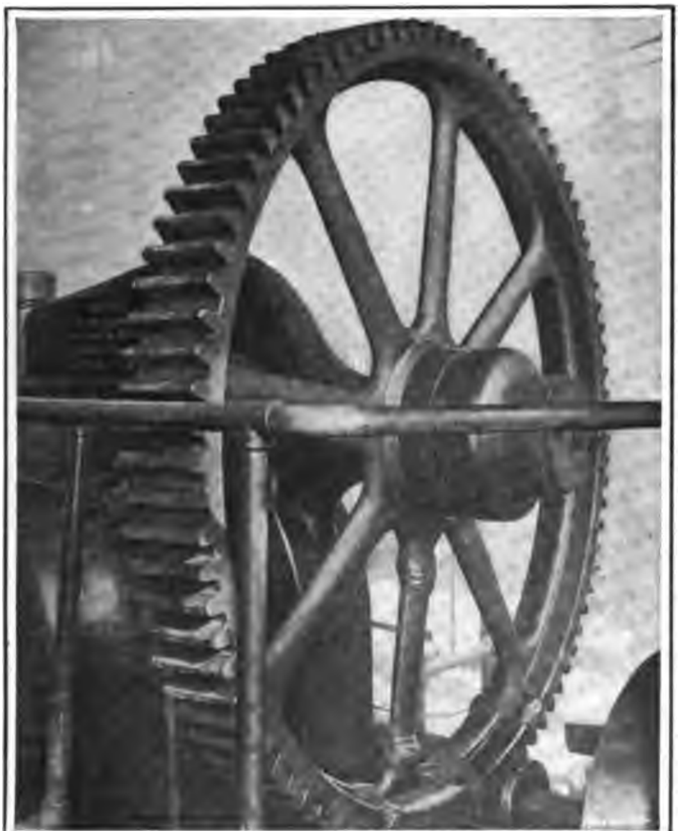


Fig. 6. Cast-iron Gear repaired by Arc Welding

after being repaired with the carbon arc. In cases of this kind, the broken part is in use again in a short time, and the delay occasioned by having to replace it with a new casting is avoided.

Another example of one of the many uses to which a welding outfit may be put is illustrated by Figs. 20 and 21, which show a

cast steel clamp of approximately 13 inches inside diameter. This was designed for assembling certain machine parts and holding them against the faceplate of the lathe for finishing. The clamp, as originally made, was in two sections (one of which is shown in the right-hand view of Fig. 20), and was intended to be

Fig. 7. Broken Teeth in Bevel Pinion repaired

tightened around the parts to be assembled, by means of bolts passing through lugs on opposite sides of the clamp. It was necessary, in order to operate the finished article successfully, that the assembled sections be drawn together with an approximately even pressure from all directions, but on trying out the device, it was found that those sections at the joints, and for

several inches on each side, did not come together properly, and after several trials, it was decided that a four-part clamp would have to be used.

To avoid the delay which would have been entailed by having the pattern returned from the foundry, making the necessary

Fig. 8. Filling in Blow-holes in Castings by Electric Arc

alteration, and getting new castings, the welding outfit was brought into play on the existing castings. Two pieces of iron were obtained and cut to shape to fit roughly between the outer flanges of the sections. These were then welded into place, half-way between the ends, as shown in the left-hand view of Fig. 20. The half rings were then cut through these lugs, and holes were

drilled for bolts, after which the clamp was again ready for use. Fig. 21 illustrates the completed four-part clamp.

The welding, in this case, was done with the carbon arc, using current of approximately 300 amperes. The operation consisted of fusing pieces of metal into the joint between the two parts to be united, and at the same time raising the metal on each side of the weld to the point of fusion. The time consumed in welding was one and one-half hour, while the machining operations for

Fig. 9. Reclamation of Worn Freight-car Knuckles

making the extra pieces of iron, and the cutting and drilling after welding required about four hours more; therefore, with a total time expenditure of five and one-half hours, and the aid of the welding outfit, there was accomplished what otherwise would have required, at a minimum estimate, from eight to ten days from the time of getting the pattern back until the new castings were machined and ready for use.

An interesting and valuable application of arc welding is shown in Figs. 22 and 23, repairs having been successfully made to a fractured steam chest and cylinder of a locomotive.

Saving Worn or Wrongly Machined Parts. — An important and interesting application of electric arc welding is met with in cases where parts that fit other machined surfaces are worn to such an extent that they would have to be scrapped. By building up by welding it is possible to replace enough metal on the worn surfaces so that they may be again machined to fit the parts into which they are assembled. This method is also applied in cases where shafts may have been machined too small for the journals into which they fit, or where, by an error, a boss or small

Fig. 10. Building up Flat Spots on Locomotive Drivers

projection may have been omitted in a casting or forging. The electric arc provides a cheap and simple method of correcting errors of this kind. In Fig. 24 is shown a valve yoke on which the stem has been built up by welding so that it can be again machined to full size. In Fig. 25 is shown an example of a 10-inch electric generator shaft which has been machined $\frac{1}{16}$ inch too small. The scrapping of this shaft would have meant a considerable loss, but by building up on the surface that was too small in diameter, as indicated in Fig. 26, and, re-machining, the shaft was saved.

Fig. 27 shows an example of a forging that required a center in one end, which was not to be present in the finished piece. A lug for the center was omitted in making the forging. It therefore became necessary to weld a small punching onto the end of the forging for a center. This simple means of providing a pro-

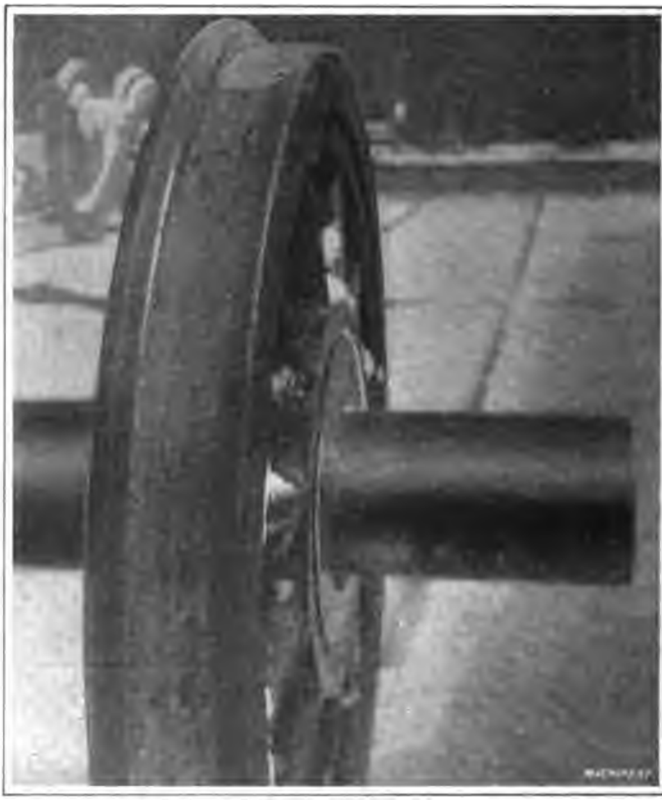


Fig. 11. Locomotive Trailer Wheel with Flat Spot Ready for Welding

jection on the end saved these forgings from being scrapped. Incidentally, the illustration shows the C & C Electric & Mfg. Co.'s face shield, which provides ample protection for the face and throat, as well as the upper part of the head.

Applications in Manufacture of New Work. — In addition to its use for repair and reclamation work, electric arc welding is

employed to a great extent in the manufacture of many sheet-metal articles. Fig. 28 shows the welding of steel sheets for gear-cases. The lugs on the inside of the gear-case are also welded into place. The welding of annealing boxes, oil-tempering tanks, etc., by means of the arc process has been found to be not only

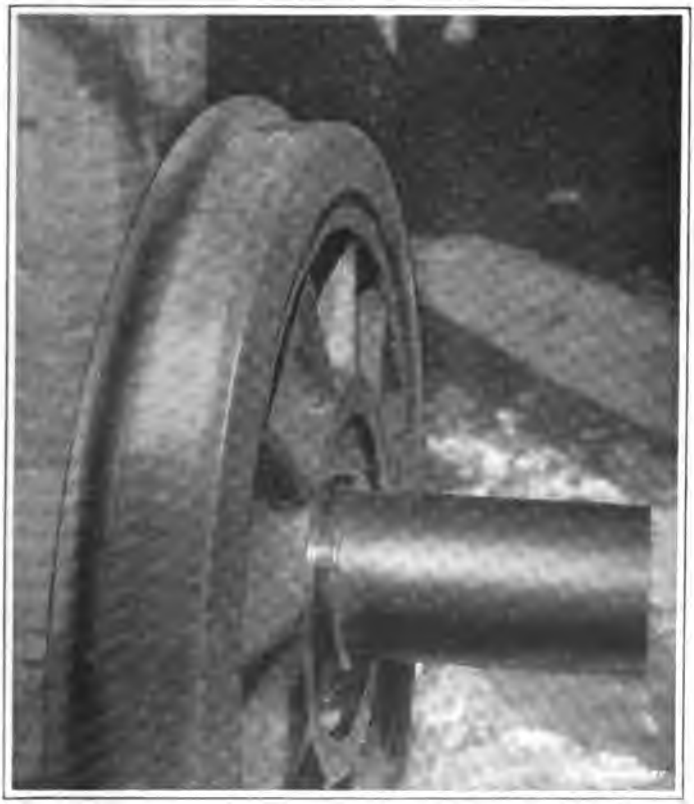


Fig. 12. Locomotive Trailer Wheel with Flat Spot built up by Arc Welding

the most successful, but also the cheapest method of making these boxes and tanks. Fig. 29 shows a plating tank that has been electrically welded. This tank is 8 feet long, 3 feet wide and 2 feet high, and is made from $\frac{1}{4}$-inch plate with a rim around the upper edge of $\frac{1}{4}$ by $1\frac{1}{4}$-inch angle-iron. A tempering tank made

Fig. 13. Fractured Section of Locomotive Frame before repairing

from $\frac{3}{16}$-inch sheets with a rim of $\frac{1}{2}$-inch boiler plate is shown in Fig. 30. The size of the tank is 30 by 21 by 15 inches. The illustration shows clearly the nature of the welded seams. Fig. 31 shows some very large work being done by the arc-welding process. The work consists of oil stills at the Standard Oil Co.'s plant in Whiting, Ind. The stills are riveted, but the joints are made tight by means of electric welding. Another example of the application of the electric arc to manufacturing work is shown in Fig. 32, where the tubes of air compressor intercoolers are

Fig. 14. Head, Flange and Branches welded in a 42-inch Tank with the Metallic Arc

welded in place at the plant of the Worthington Pump & Machinery Corporation, Cincinnati, Ohio.

Another example of electric arc welding is found in the welding of steel barrels by the Standard Oil Co. In these barrels, the

longitudinal seam is welded electrically. The bulge of the barrel is then obtained by hydraulic pressure, showing that the efficiency of the weld is high and that the heat of the arc has not affected the strength of the steel to any appreciable extent.

Applications of Electric Welding to Railroad Shops. — There are a great number of instances where electric arc welding may be used to advantage in railroad shops. In fact, the railroad shop offers one of the greatest opportunities for the application of the process. It is used to a large extent in many shops in building-up operations. Practically every steel casting on a locomotive is subject to wear at several points. Where worn, the metal may be built up again, by means of the metal electrode process, both cheaply and rapidly. Most of these building-up operations are done with a $\frac{5}{32}$- or $\frac{3}{16}$-inch electrode. The use of smaller electrodes is not economical, owing to the slow progress of the operation. The use of larger electrodes is inadvisable on account of the difficulty in controlling the metal. Metallic electrodes should be used in preference to carbon electrodes for welding of this kind, for the following reasons: (1) Steel castings welded with a carbon arc would have to be annealed, which entails additional cost and delay. (2) The metal can be deposited at the exact place where it is required more accurately by the metal electrode process than by the carbon electrode method; and, therefore, while the carbon arc process is somewhat more rapid than the metallic arc method, the time saved in the welding operation by the carbon arc would be lost in the machining operation

Fig. 15. Section of Locomotive Frame shown in Fig. 13 after repairing

on account of the inaccuracy of the location of the deposited metal. (3) The operator requires less skill in the use of the metallic arc than in the use of the carbon arc when the process is used for building-up operations; when applying metal with a

Fig. 16. Fractured Mud-ring of Locomotive Firebox prepared for Making the Welds

Fig. 17. Completed Weld with Sections of the Throat Sheet replaced

metallic electrode, the operator is forced to move along as fast as the metal is deposited; with the carbon electrode, he may dwell longer, but is, however, likely thereby to produce a burned spot. (4) Hard spots are not produced when the metal electrode process is used for building up.

Flue Welding. — Electric arc welding is also frequently used for welding in the firebox and for flue welding. The process recommended by a sub-committee of the Association of Railway Electrical Engineers is as follows: Welding in the firebox should

Fig. 18. Broken Casting from a Woodworking Machine

be done with a $\frac{1}{8}$- or $\frac{5}{32}$-inch electrode. The best metal is obtained in the weld with these sizes. The amount of heat is as small as can be economically used. It is evident that, owing to trouble from expansion and contraction, the quantity of heat it is possible to use in welding flues or firebox sheets is limited. The

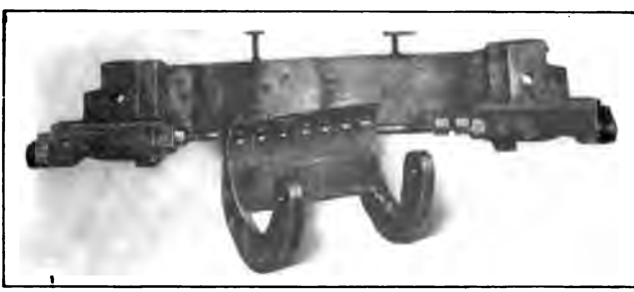


Fig. 19. Casting shown in Fig. 18 repaired with the Carbon Arc

ideal preparation of a set of flues for welding is as follows: (1) Put flues in exactly as if they were not to be welded. (2) Fire the boiler, or, better still, send the engine out for a run. The object is to burn the oil out from under the beads of the flues. (3) The flue sheet should then be brushed with a stiff wire brush or sand-blasted. The object is to eliminate, as far as possible, the

scale of oxide on the flue sheet and flues. Iron oxide is not a good conductor of electricity and causes difficulties with the arc, which, in turn, may produce a poor weld.

The welding of 2-inch flues is best done with a $\frac{1}{8}$-inch electrode. On sand-blasted flue sheets, from 90 to 100 amperes is enough

Fig. 20. Steel Casting to which Bolt Lug was electrically welded, as shown to the Left

Fig. 21. Four-part Clamp with electrically welded Bolt Lugs

current. Flue sheets that have a thick coat of oxide require from 120 to 130 amperes with this size of wire, and the weld will not be satisfactory. Five-inch flues should be welded with a $\frac{5}{32}$-inch electrode and with from 120 to 140 amperes, depending upon the condition of the flue sheet.

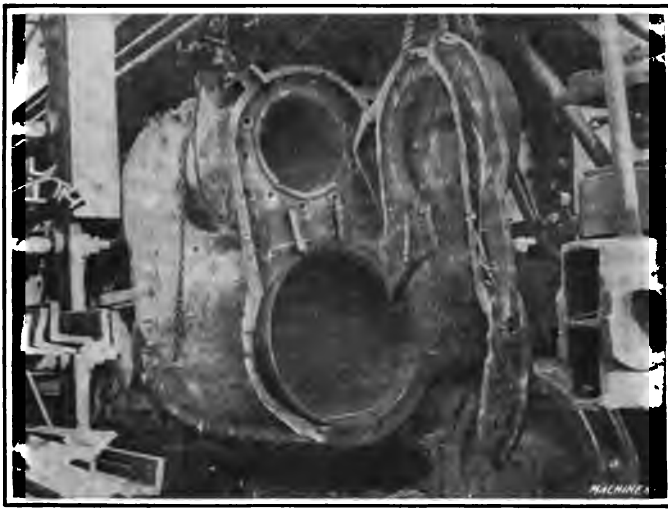


Fig. 22. Fractured Steam Chest and Cylinder on Locomotive to be welded

Fig. 23. View of Parts shown in Fig. 22 after being repaired with Wilson Electric Welder

Cracks or Seams. — Cracks and patch seams offer the most difficult problems to the operator. A crack should be located and a ½-inch hole drilled at least two inches beyond each end. The edges of the crack should then be beveled so that the operator can reach them to make the weld. On horizontal cracks, the lower edge does not need to be beveled, but should be chipped to produce a square edge. The upper edge should be beveled at least 45 degrees. Vertical cracks should be beveled from 30 to 45 degrees on each side. The less material removed from the crack the better. All welds should be made with the least possible amount of metal between the edges of the original material.

Fig. 24. Worn Valve-yoke Stem built up by Welding, Ready for Machining

If the crack or seam is a long one, the metal should be put in alternate sections of from four to six inches long. The operator should put one layer of metal in each of these alternate sections, starting near the center of the seam or crack. The open sections can then be filled, starting at the coolest point. Successive layers of metal can then be applied until the seam is completed. Wherever possible, at least 30 per cent of reinforcing should be applied so that the cross-section through the weld is 30 per cent greater than the section of the original plate. After each layer of metal is welded into the seam, it should be thoroughly brushed with a stiff wire brush to remove as much of the oxide as possible. Where the sand-blast is available and can be used on the job, the results will justify the expenditure of time necessary to clean the

metal between the layers. The same general care should be taken in the welding of locomotive frames as in the case of the boiler plate of the firebox.

Examples of Railway Shop Welding. — A number of examples of the application of electric welding to railroad work are shown

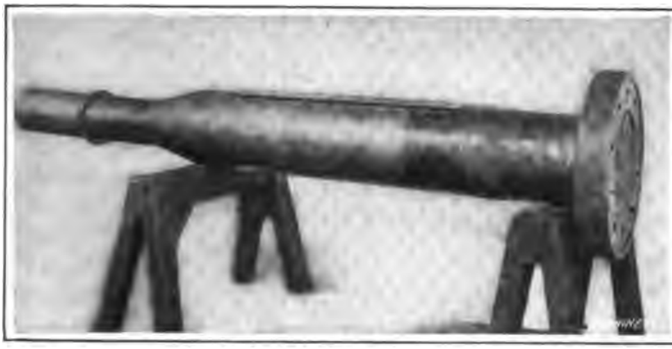


Fig. 25. Ten-inch Electric Generator Shaft machined 1/16 Inch too Small in Diameter

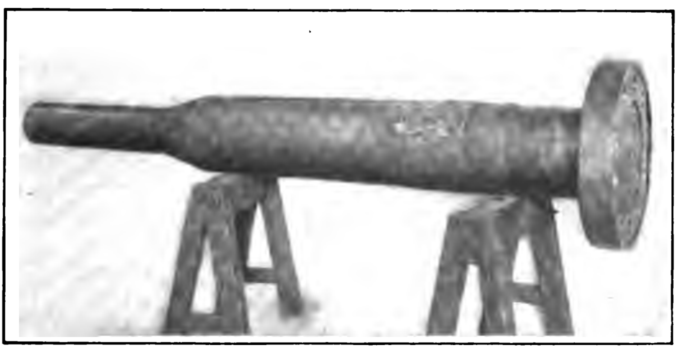


Fig. 26. Same Shaft as shown in Fig. 25 after being built up by Welding, Ready to be machined

in Figs. 33 to 40, inclusive. Fig. 33 shows the repairing of a locomotive boiler at the Toledo & Ohio Central shops at Bucyrus, Ohio. Figs. 34 and 35 show a patch 10 inches wide and 5 feet long being riveted to the mud-ring of a locomotive on the Central Railroad of New Jersey. The vacant space indicated is left for

welding. Fig. 35 shows the patch after being welded in place. Figs. 36 and 37 show the application of electric welding of superheater flues on the Atlantic Coast Line. Fig. 36 shows the flues ready for welding, and Fig. 37, the job completed. Fig. 38 shows a locomotive firebox with electric arc-welded flue sheets, side sheets, flues, superheater tubes, and brick arc studs, indicating the wide range of work for which the process is adapted.

Fig. 27. Welding a Lug to End of Steel Forging for a Center

Railway Shop Organization for Arc Welding. — The importance of the welding operations in a locomotive shop or engine house is so great that it is necessary for the work to be done under the direction of a competent and responsible member of the railroad organization, and this importance has been recognized to the extent of having been embodied in a report made by a subcommittee of the Association of Railway Electrical Engineers. On a large system where welding is done at several shops and engine houses, it has been found that, unless some special effort is made in regard to uniform supervision, the practice of one shop

has not usually conformed with the practice of the other shops of the system. This leads to a situation in which it is impossible to place the responsibility for the success or failure of the process. A very successful solution to this problem has been made on several systems by the appointment of a supervisor of electric welding who is responsible directly to the general superintendent of motive power. The supervisor of electric welding makes the practice of the several shops uniform, so that the failure of one

Fig. 28. Manufacturing Gear Guards from Sheet Steel by Electric Welding

shop to obtain results from a process can be traced to its origin. The supervisor of electric welding must find a successful way of doing each job and require every shop to perform the operation according to his instructions.

When failures of certain operations are reported, the supervisor of electric welding can readily locate the trouble, since it can only be due to the failure of some particular shop to follow his instructions. In this plan the operators in each shop are

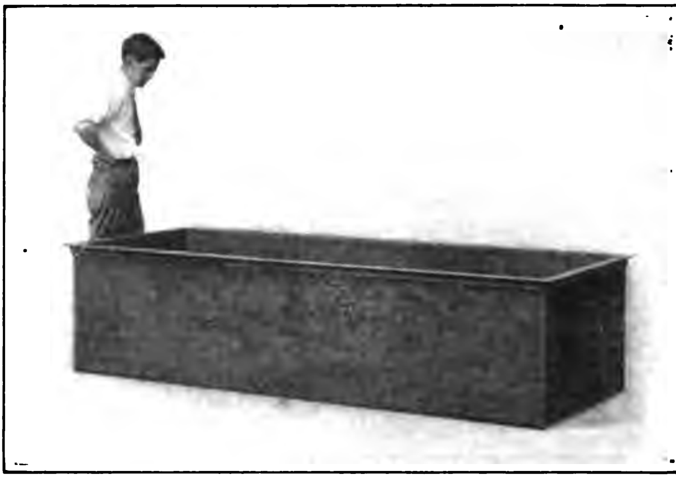


Fig. 29. Electrically Arc-welded Plating Tank

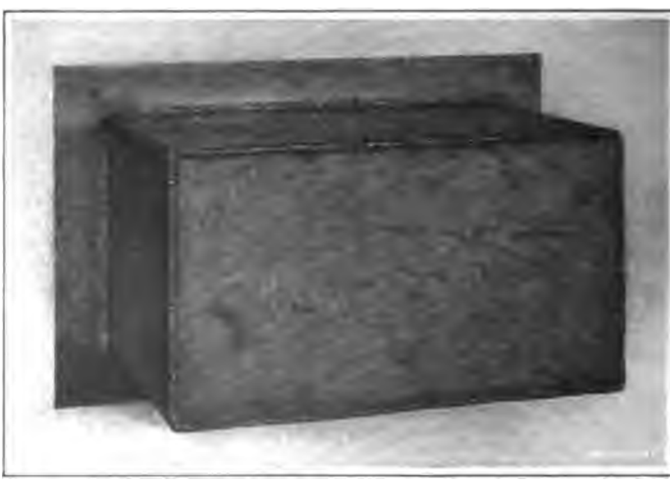


Fig. 30. Electrically Welded Tempering Tank, showing Character of Welds

responsible to the local shop authorities in the usual way, and are responsible only to the supervisor of electric welding for the manner in which they perform the welding operations. The operators in a given shop are usually in charge of a foreman opera-

tor, who assigns them to individual jobs and is responsible for their following instructions of the welding supervisor. Operators are obtained in most cases from the shop organization. On roads where an apprenticeship training is provided, most of the operators are men who have just completed the apprentice work. It is desirable to have operators who have had general experience in a railroad shop. In shops which have a local electrician, the

Fig. 31. Welding Oil Still's by Electric Arc

care of the electric arc-welding equipment is handled by him. In engine houses, the operator of the equipment is usually trained to give the equipment whatever care is necessary.

Standardization of Operations. — The tendency at the present time is to standardize the welding operations in the same manner that the machine shop and other operations have been standardized. Where welding operations are thoroughly standardized, the work can be paid for on a piece-work basis. The standardization of welding operations is comparatively simple. Ninety-

five per cent of the electric arc welding done in railroad shops is on operations which can be standardized. The following factors should be determined for each job of this nature: 1. Size of electrode. 2. Kind of electrode. 3. Current in the arc. 4. Time required for the operation.

Capacity of Equipment for Railway Work. — It is considered that, at the present time, 150 amperes capacity for each five tracks in a locomotive shop or for each fifteen tracks in an engine house is sufficient capacity for electric arc-welding equipments.

Fig. 32. Welding Air Compressor Intercoolers by Electric Arc

Application of Welding Process in Steel Works. — The electric arc-welding process has been applied to a considerable extent in steel mills, the steel companies having found that much of the metal formerly scrapped, such as broken shafts, rolls with worn wobblers, rolls worn in the passes, cracked spindles, cracked ladles, cracked rolling mill frames, etc., can be successfully welded and rendered practically as good as when new. Another application of the electric arc welding outfit in connection with blast furnaces is for the burning out of clogged tap holes and tuyeres. The clogging of the tap holes in a blast furnace causes the shutting

down of the furnace and produces an immense loss if the trouble is not immediately remedied. It has been found that, by using a light graphite electrode and a current of from 800 to 1000 amperes, the electric arc will quickly burn out the clogged tap holes. About 36 inches per hour is the rate at which the burning or cutting may be done on this class of work.

Application in Foundries and Machine Shops. — In addition to the ordinary work of welding in a machine shop, it has been found that the welding of annealing boxes by means of the arc

Fig. 33. Repairing a Locomotive Boiler by Arc Welding

process is not only the most successful, but also the cheapest, method of making these boxes. The electric arc also provides a rapid and economical means for cutting off heavy risers on large castings, repairing castings which are defective and which would otherwise be scrapped, filling blow-holes and cracks, and building on pads and lugs.

Application in the Manufacture of Tanks, Boilers, and Steel Barrels. — The electric arc-welding process has been applied to an ever-increasing extent in the manufacture of tanks and barrels which were formerly either brazed or riveted. Heads are now

Fig. 34. Patch riveted to Mud-ring Ready for Welding

Fig. 35. Patch shown in Fig. 34 after being welded in Place

welded in tanks for gas storage, and various companies weld the seams in steel barrels. The process is of considerable advantage because, by simply changing from a metallic to a carbon electrode, holes can be quickly and cheaply cut for inlets and outlets.

Air reservoirs used in connection with air-brake apparatus are now welded in this manner. In the welding of longitudinal seams, the cost of making shells for tanks and low-pressure boilers is greatly reduced, and, while the process possibly would

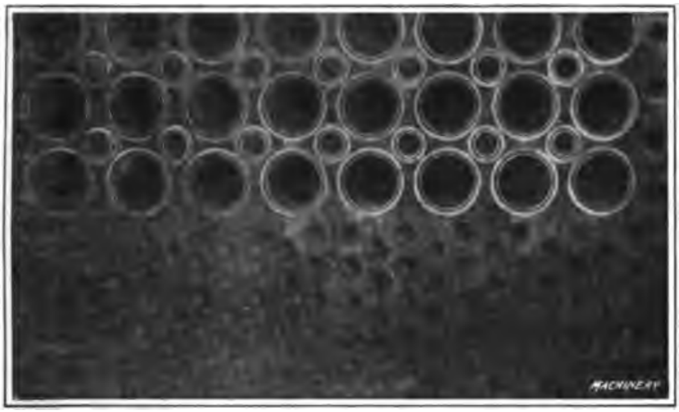


Fig. 36. Superheater Flues Ready for Welding

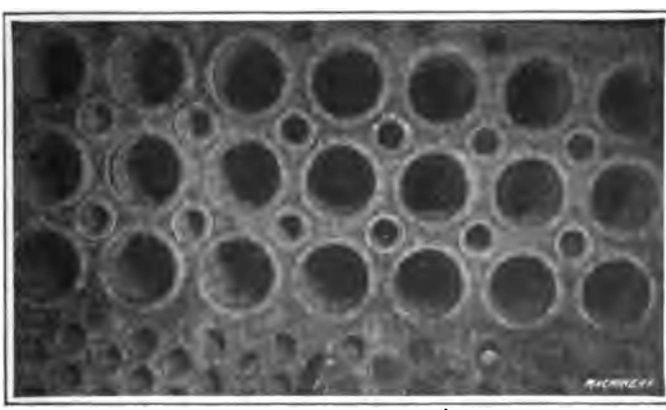


Fig. 37. Superheater Flues after Welding is completed

not be recommended for high-pressure steam boiler work, on account of the difficulty of inspecting whether the weld has been properly made or not, a careful operator can obtain a strength in the weld nearly equal to that in the plate itself.

In pipe work, the electric arc-welding process has proved of great value, because it is possible to weld pipes into complicated forms and to obtain great strength at the joints. Special pipe fittings are eliminated and leakage is provided against. A better appearance and more convenient arrangement can also often be made in a large piping system by the use of welded joints.

Procedure in Tank Welding. — The best method to employ when welding tanks from plates that are $\frac{1}{4}$ inch or more in thick-

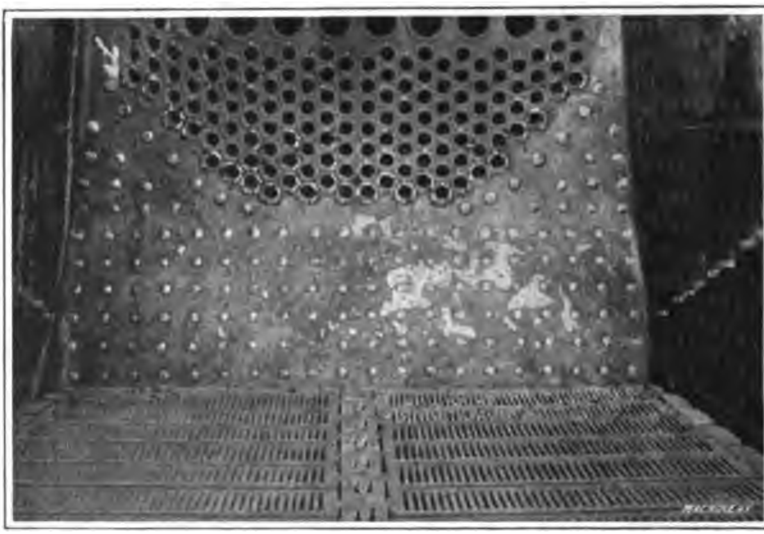


Fig. 38. Locomotive Firebox with Electrically Arc-welded Flue Sheets, Side Sheets, Flues, Superheater Tubes, and Brick Arc Studs

ness is to make a lap-joint and weld at the joint on both sides. In making lap-welds, the plates are overlapped an amount about equal to that required for single-row riveting. The best way of holding the plates together while welding is by drilling holes for bolts about 18 inches or 2 feet apart, and inserting bolts to hold the plates together while welding. When the welding is completed, the bolts are removed and the bolt holes are filled up by using the carbon arc and some filling material. The cost of making joints by lap-welding, when the preparation in handling the plates is considered, should be less than for butt-welding, be-

cause it is easier to assemble and hold the plates for lap-welding. When plates are greater than ¼ inch in thickness, however, they may be beveled and butt-welded. For plates more than ½ inch in thickness, it is best to bevel the plates from both sides toward the center, forming a vee on each side, and then weld the plate from both sides. As this reduces the amount of filling by 50 per cent, the time may be considered as reduced to 40 per cent. This method can be applied, of course, only when both sides of the plate are accessible.

For plates ¾ inch and heavier, carbon or graphite electrodes are sometimes preferable to metallic electrodes. Especially is this true when plates 1 inch thick or over are welded.

Fig. 39. Locomotive Bell welded by Arc Process

Welding High-speed Steel to Machine Steel. — On account of the high price of high-speed steel, various means have been developed for welding high-speed steel tips to machine steel shanks. In this way, the high first cost of a high-speed steel tool made solidly from the expensive metal is avoided, and, furthermore, when the tool is worn out, costly metal is not scrapped in the scrapping of the shank. Also, worn-out high-speed steel tools can be cut to the proper size and utilized for tips of tools that are welded. The Westinghouse Electric & Mfg. Co.,

which at the present time uses cutting tools with high-speed steel tips and machine steel shanks in many of its planers and lathes, has found the electric arc process more satisfactory and cheaper for this purpose than any other process. This conclusion has been reached after tests employing both the oxy-acetylene and the forging methods. The best result, when using the Westinghouse welding outfit, is obtained with a current of approximately 100 amperes and with a voltage in the welding circuit of from 60 to

Fig. 40. Four Operators working independently from the Same Generator

70 volts. A $\frac{5}{32}$-inch Swedish iron electrode is used. The work should not be hurried if good results are expected, but an experienced operator should be able to make from 25 to 30 welds of tools having a cross-section of about $1\frac{1}{2}$ inch in a day of nine hours. The method of making the weld is as follows:

The high-speed steel tip is first "tacked" to the machine steel shank and the whole preheated. After fluxing with borax, welding is started. After welding, the tool is immediately laid in mica dust to cool gradually. It is then rough-ground, hard-

ened, and tempered, after which the finish-grinding is accomplished, when the tool is ready for use. Reinforcing metal is built out around the tip, which serves both to give a larger radiating surface and to afford a larger conducting path back to the shank of the tool, thus keeping down the temperature at the cutting edge. The machine steel shank may be of any length desired, and of cold-rolled, hot-rolled, or carbon steel, while the high-speed steel tip should be short.

Fig. 41. Welding Bronze Sleeve of Steamship Tailshaft

Welding Non-ferrous Metals. — An interesting application of electric arc welding is that of welding locomotive bells. Fig. 39 shows the cracked bell repaired, the dotted lines indicating the weld. The cost of this welding is \$2.60, and the saving by welding is \$7.50. This example of electric welding is especially interesting on account of the fact that bell metal is being welded. Fig. 40 shows the welding work on the bells being carried out. The work is done by the carbon arc, using a filling-in rod. Other welders are also shown at work using current from the same generator, but each welder having a separate control panel. The

control equipment shown in the background is that of the Wilson Welder & Metals Co.

Another example of the welding of non-ferrous metals by the electric arc is shown in Fig. 41, where a General Electric Co.'s equipment is used for welding bronze sleeves for a steamship tailshaft by using a bronze electrode. The shaft is 13 inches in diameter and the sleeve is welded together from three sections, the total length of the sleeve being 13 feet. The metal being

Fig. 42. Appearance of Cuts made in Boiler Plate by Carbon Electrode

welded is $\frac{3}{4}$ inch thick; the edges are beveled preparatory to welding.

Cutting or Melting Metal with a Carbon Electrode. — When cutting or melting metal with the electric arc, a carbon electrode must be used. The electrode is operated in a manner similar to that used when employing a gas torch for metal cutting. The electric arc actually melts the metal away, it being held at one point until fusion occurs and the melted metal runs off, after which the arc is slightly advanced, and in this way a path through the metal is gradually melted. The width of the groove cut depends upon the size of the electrode used and on the skill of the operator in advancing the electrode along a straight line. The cut will be slightly wider than the diameter of the electrode, and is also wider for thick sections than for thin ones, as the electrode

will melt away more metal when the arc has to be played on the bottom of the cut. It is not possible to obtain very smooth edges of the cut on account of the fact that some parts of molten metal will not run away evenly, and also because the arc has a tendency to jump from one point to another, causing an uneven cut. Fig. 42 shows an illustration of cuts made by the carbon arc in ½-inch boiler plate. For cutting steel plate where a smooth edge is required and much cutting is to be done, the oxy-acetylene process

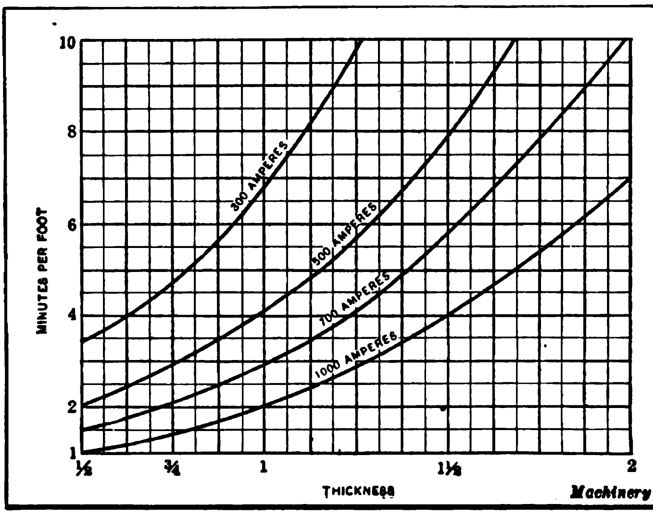


Fig. 43. Cutting Speeds when cutting Sheet Steel by Carbon Electrode

is conceded by the makers of arc-welding apparatus to be preferable, because a smoother cut is obtained. For cutting cast iron, however, the electric arc is equal or superior to the gas torch, and for cutting off heavy risers in the foundry on both steel and iron castings, and for cutting up scrap where a ragged edge is of no importance, the electric arc is used to advantage. Fig. 43 shows a diagram of approximate cutting speeds for different thicknesses of sheet steel and for various current values. The cutting speed is lower than is possible with the gas process, which burns away the metal rather than melts it, but with a reasonable

power rate, the cost of cutting by the arc is much lower than the cost of cutting by means of gas, in a great many cases. Where the metal is rusty or where blow-holes are encountered in steel castings, the electric arc will cut the metal with equal ease, while

Fig. 44. A Collection of Castings with Heavy Risers which are cut off by a Carbon Arc

the gas process cannot be employed in cases of this kind. The metallic electrode cannot be used for cutting metals.

Fig. 44 shows a number of steel castings in the shops of the Marion Steam Shovel Co., showing heavy risers which are to be cut by means of the electric arc.

CHAPTER IX

WELDING TRANSFORMER TANKS BY THE ELECTRIC ARC

THE electric arc-welding process has been developed and applied to a great extent in the welding of seams in transformer tanks at the Pittsfield Works of the General Electric Co. The method has been found superior for this work to all other methods used or investigated by the company. At one time, many of the transformer tanks were riveted; this was more expensive and less satisfactory than the welding, on account of the fact that it was difficult to obtain absolutely leakproof tanks by the riveting process, oil having a tendency to seep through even the most minute openings. In its efforts to obtain a better method than riveting, the company used the oxy-acetylene method to a large extent, for several years. This method had the advantage of producing satisfactory oil-tight welds, but was found to be quite costly. In an effort to reduce the manufacturing cost, electric arc welding was tried and found to meet the requirements, producing a satisfactory weld at a decreased cost; hence, practically all the sheet-metal transformer tanks made at the Pittsfield Works are now welded by the electric arc method. In addition, the electric arc is used on miscellaneous welding about the plant.

Welds are made in metal varying all the way from $\frac{1}{16}$ to $\frac{3}{4}$ inch in thickness. Steel plate as thin as $\frac{1}{16}$ inch is lap-welded, and butt-welds may be made in metal as thin as $\frac{1}{8}$ inch. Thin metal like this requires no beveling at the edges of the sheet preparatory to welding. If metal thinner than $\frac{1}{16}$ inch is to be welded, the arc process is found unsuitable, because the arc will burn the metal. When metal from $\frac{1}{4}$ to $\frac{5}{8}$ inch in thickness is welded, it is beveled on one side, and steel plate $\frac{3}{4}$ inch or more thick is beveled on both sides, when seams are made. When used against the transformer shell for a bottom, it is beveled on only one side. Transformer tanks from the smallest size and up to those 10 feet

in diameter and 14 feet high (the latter being made from $\frac{5}{8}$-inch boiler plate) have all their longitudinal seams welded in this manner, and the sheet-steel rim at the bottom is also welded to the tank by the electric arc. Cast-iron bands at the top of some transformers cannot be welded to the cylindrical steel shell, but must be riveted or joined by bolts; but the arc-welding process is used for welding around the heads of the rivets or bolts on the

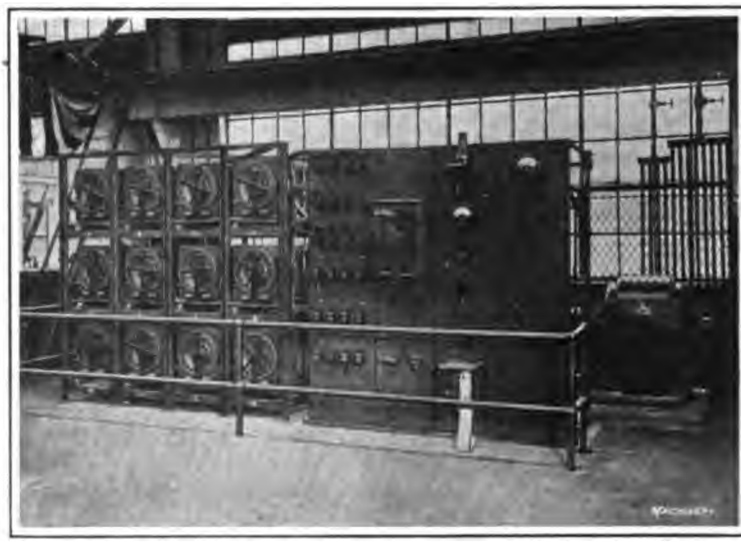


Fig. 1. Welding Equipment, showing Part of Generator Set and Switchboard

inside, in order to insure that there will be no leakage at those points.

Equipment used for Welding. — The equipment used for welding in the Pittsfield plant consists of a motor-generator set which generates 75 volts direct current. The capacity of the generator is 150 kilowatts; it is driven by a 225-horsepower induction motor supplied with 60-cycle alternating current. The direct current from the generator passes to direct-current busses on which a constant voltage is maintained by a voltage regulator. Attached to the busses are twelve separate welding circuits, so that each welder can work independently. On the switchboard

panel shown in Fig. 1, twelve rheostats are mounted together with the remote-control switches in series with each welding circuit, so that the welder does not need to leave the place where he works in order to control the current. In series with the rheostats is a reactance coil, the object of which is to maintain the arc if drawn out too far, and also to reduce the rush of current when striking the arc. All this apparatus is mounted on or adjacent to the main switchboard and the generator set.

On the floor where the welding is done, separate stations are provided, with one panel for each welder. These are placed adjacent to the spot where the work will be done. From these panels, the welder adjusts the current, as indicated by the ammeter mounted on the panel. A plug is provided which is pulled out when the operator is not working. On the holder for the electrode, a switch is also provided which may be snapped to open or close the circuit.

Electrodes. — The electrodes for welding sheet steel and boiler plate, used in the construction of transformer tanks, are bought in the form of wire coils or rolls from which the electrodes are cut off in lengths of about 18 inches, and straightened. Swedish iron wire is used for this purpose, when obtainable, but similar wire, known as "Toncan wire," is also obtainable in the United States, the Pittsfield Works obtaining their supply from the Washburn Wire Co., Phillipsdale, R. I. The wire comes in sizes of from $\frac{1}{16}$ to $\frac{3}{16}$ inch in diameter. The carbon electrodes used for certain work are tapered in shape, being about $\frac{1}{8}$ inch in diameter at the small end, and $\frac{3}{8}$ inch at the large end. The length is about 5 inches, when new. When used, the carbon electrode gradually burns away, but, being tapered, it maintains practically the same diameter at the point as it diminishes in length. The carbon electrodes are made from a composition similar to that from which arc-lamp carbons are made. Graphite electrodes may also be used, but they do not last as long as the carbon electrodes.

Protection of Welders. — The welders wear a hood, as shown in Fig. 2, to protect their head from the rays from the arc and their eyes from the intense light, and also gloves to protect their

hands from burns. The glass in the welding hood consists of three thicknesses: one medium green glass, one dark red glass, and one plain white window glass. The latter is placed outside of the colored glass, the object being to protect the colored glass from the deposit of atomized metal which, during welding, gradually settles on the glass. The piece of plain glass, when useless on account of these metal deposits from the arc, can be cheaply replaced.

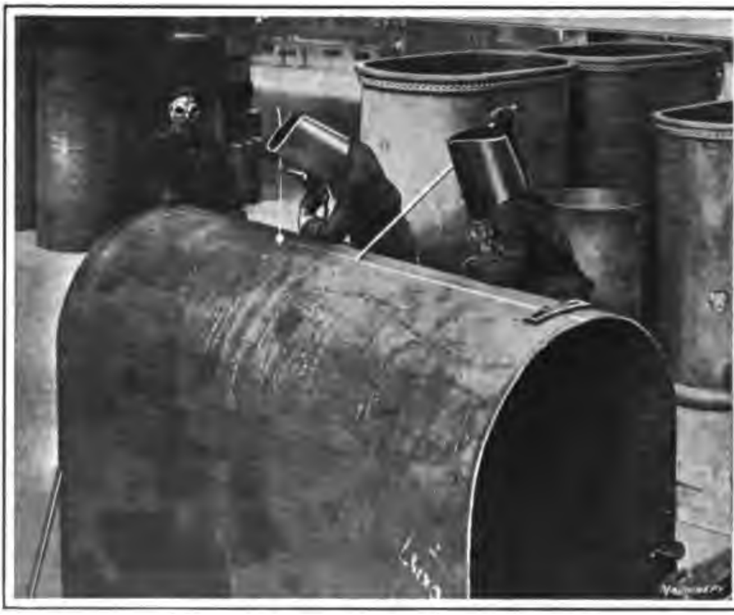


Fig. 2. Welding of Seam in Transformer Tank, showing Method employed for Maintaining Proper Space between Plates being welded

Preparation for Welding. — Comparatively little preparation is required for the welding of sheet metals. In the case of thin metals, the pieces are merely held together by suitable clamps and lightly tapped with a hammer so that they will fit properly. In the case of long welds, it is necessary to separate the plates slightly, previous to welding, because of the expansion that takes place during the welding operation. The usual method is to separate the plates $\frac{1}{8}$ inch at the end where the weld is to

begin, and to increase the space between the edges of the plates at the rate of 2 per cent of the length. It has been found that, by placing the plates in this position, they will come together as the weld proceeds along the seam. As already mentioned, thin work is not beveled or prepared in any way, while thick plates are beveled either on one or on both sides.

In Fig. 2 is shown a longitudinal seam of a tank being welded. As indicated, the plates are held apart by a clamp and bolts at one end of the seam, while the welder proceeds with his work from the other end. An assistant uses a bar for holding the plates apart a short distance from the weld, as shown. In Fig. 3 is illustrated the base of a tank prepared for electric arc welding. It should be noted that there is a space left between the tank itself and its base, but that spot-welds are provided along the edge of the shell for holding the base and shell together while the arc-welding operation proceeds.

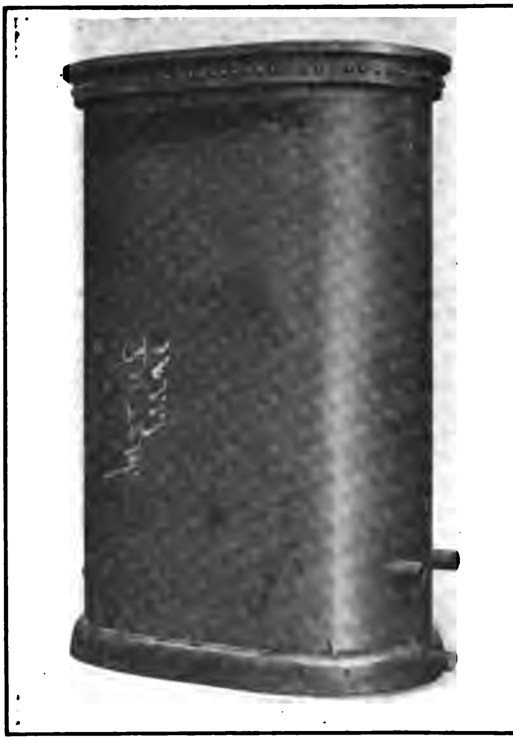


Fig. 3. Base of Tank with Space between Base and Shell and Spot-welds holding Base and Shell together

The Welding Operation. — The welding operation is comparatively simple, and operators can be taught to become proficient in a comparatively short time. The best welders are

those who have had previous experience with oxy-acetylene welding. They will learn to do good arc welding in about four weeks, but a " green " man will require from eight to ten weeks to become proficient. It is somewhat easier to manipulate the carbon arc than the metallic arc, on account of the fact that the

Fig. 4. Arc Welding of Corrugated Sheet Steel for Small Transformer Tanks, using Carbon Electrode

former is longer and does not break as easily if the operator does not hold his hand steady. The arc, while welding by the metallic electrode, is not more than $\frac{1}{8}$ inch long, and it requires considerable practice to move the electrode steadily along the weld without either touching the work or bringing the electrode so far away from the work that the arc is broken. The metallic arc is used for welding practically all of the sheet-metal work that

is butt-welded, and most of that which is lap-welded. The carbon arc is used only in the case of welding thin sheets of corrugated metal used for smaller transformer tanks. In that case, sheets from $\frac{1}{16}$ to $\frac{3}{32}$ inch in thickness are fitted together, side by side, so that the edges of both sheets face upward, as shown in Fig. 4. The carbon electrode is then moved along the joint, melting the metal at the edges and welding or fusing together

Fig. 5. Special Welding Machine in which the Electrode is Guided and Fed along the Seam, Developed in the Pittsfield Works of the General Electric Co.

the two sheets without using a welding rod or supplying any additional metal. The reason for using the carbon arc is that the metal is melted much more rapidly in this way than by the metallic arc, but, for general welding, the metallic arc is preferred, because it produces a neater job, the seam being much more uniform in thickness and the metal deposited more evenly. Most of the welding is done by hand, but special welding machines, as shown in Fig. 5, have been developed, in which the electrode is guided along the seam at a rate of advance that has been determined to be correct for each kind of work. In addition

to automatically feeding the electrode along the work, the machine is also provided with adjustment for taking care of the

Fig. 6. Tank with Six Seams that were welded by Electric Arc-welding Process

Fig. 7. Inside View, showing Metal forced through Seam and Reinforcement at End of Seam

reduction in length of the electrode as the welding progresses, the electrode being fed downwards towards the weld at the required rate.

In Fig. 8 are shown three examples of tank welding. In the small tank to the left, the longitudinal seam, as well as the bottom, is arc-welded. In the tank in the middle, the longitudinal seam is welded, and in the tank to the right, the longitudinal seam and the seam between the shell and the base have been welded. Fig. 6 shows an interesting example of a shell welded together from six separate pieces or segments. Fig. 7 shows the upper end of the inside of an electrically arc-welded seam in

Fig. 8. Tanks welded by Electric Arc, using Metallic Electrode

a tank. This view indicates how the metal from the electrode is forced clear through the seam, as indicated to the right, and also shows, to the left, the reinforcement at the end of the seam, where the seam is also welded from the inside. Fig. 9 indicates what can be done in the way of finishing welded tanks so that the joint is practically imperceptible. The tank shown has welded seams at the corners and the surface of the weld has been ground off to present a smooth appearance, the weld being reinforced on the inside. When a tank made in this manner is painted, it would be impossible to find any joints whatever on the outside.

In Fig. 10 is shown a view of the bottom of a large tank where a $\frac{3}{4}$-inch base is welded to a $\frac{3}{8}$-inch shell. The size of the tank is about 6 by 12 by 14 feet high. The illustration shows clearly the character of the weld.

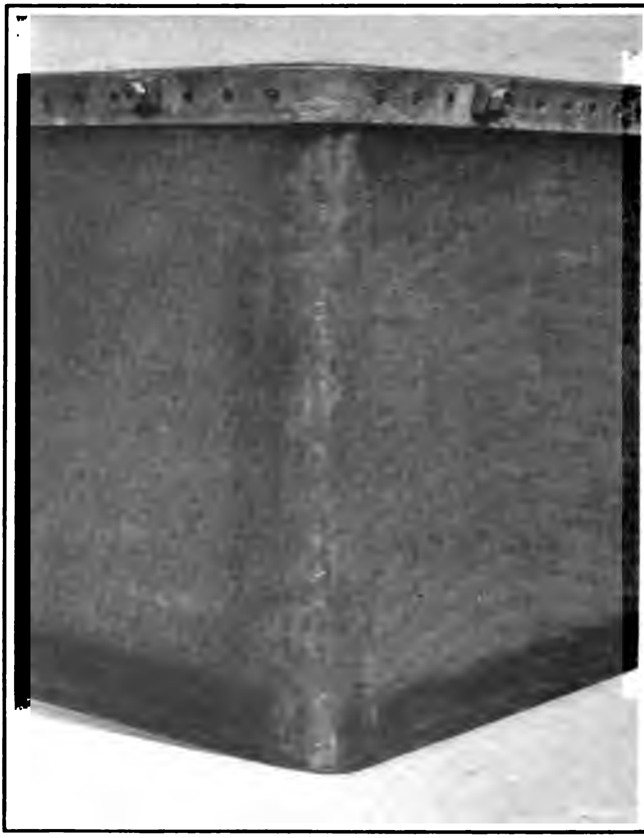


Fig. 9. Tank with Welded Seam, which has been ground Smooth

Examples of the Application of Arc Welding. — In addition to the welding of the longitudinal seams of the transformer tanks, the electric arc is used for a number of other welding operations in connection with the manufacture of transformers. The tubes are welded into oil-cooled transformers by the electric arc. The tubes are bent, inserted, expanded, and then welded.

It has been found that this process is far superior to using oxy-acetylene for welding. In the past, out of 100 tubes welded by the oxy-acetylene process, about 10 per cent developed leaks. When welded with the arc-welding process, however, out of 100

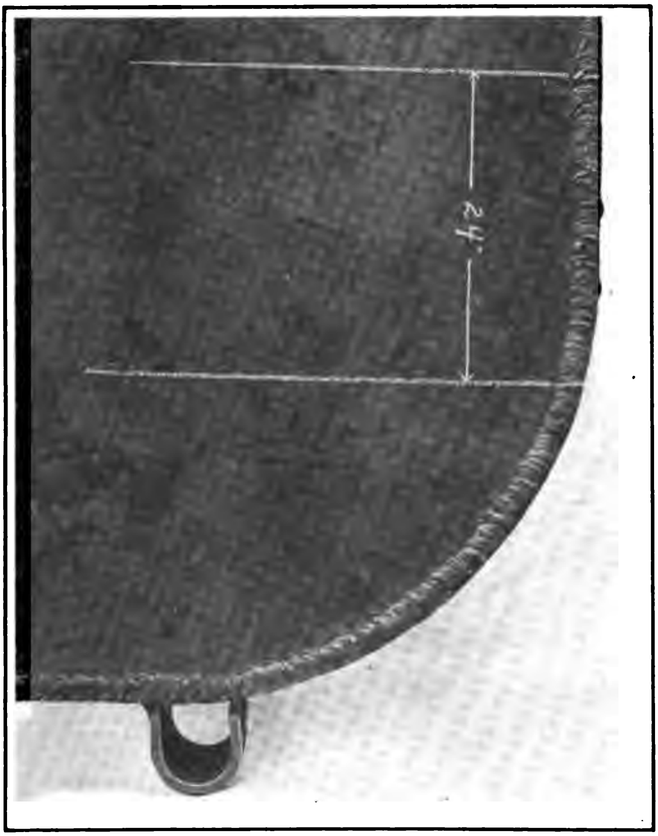


Fig. 10. View of Seam in Tank where Bottom is welded to Shell

tubes, only an average of one tube is found to leak. Fig. 11 shows the tubes in one of these tanks expanded preparatory to electric arc welding. Fig. 12 shows the tubes welded to the transformer shell, while Fig. 13 shows the completed tubular transformer tank in which the base and tubes are welded by the arc-welding process.

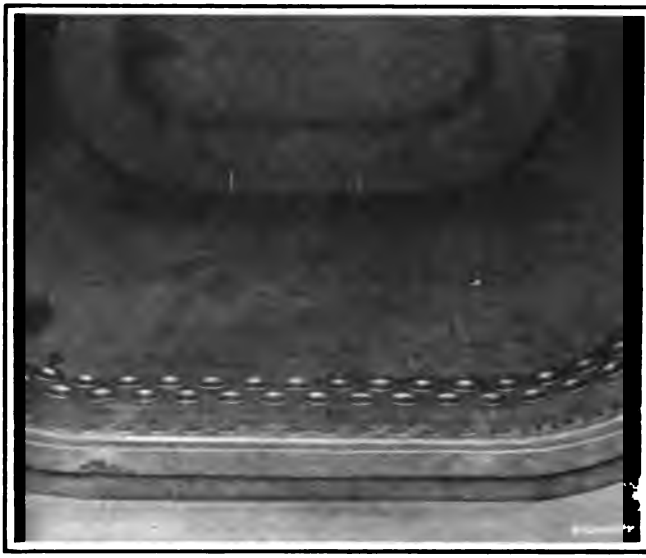


Fig. 11. Tubular Transformer Tank, showing Tubes expanded preparatory to Welding

Fig. 12. Tubular Transformer Tank, showing Tubes after having been welded to Shell

Bolt heads and rivets are welded around the heads in order to insure oil-tightness. Fig. 14 shows a section of a riveted joint indicating the probability of leakage between the rivets and the

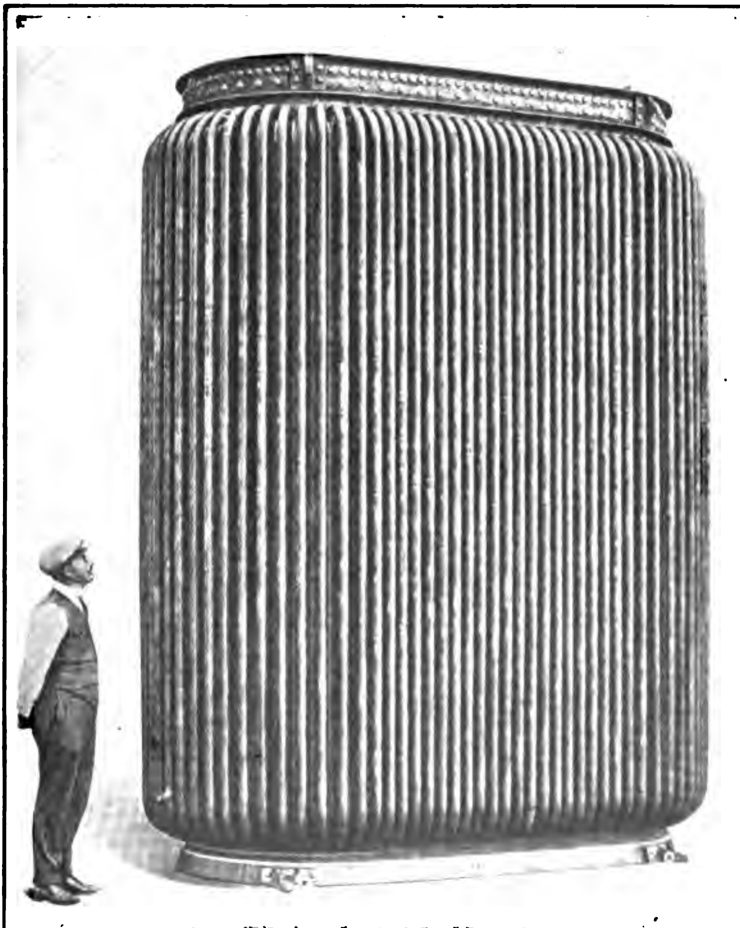


Fig. 13. Tubular Transformer Tank, Base, and Tubes welded by Electric Arc

plates, were it not for the welding at *A*, which provides for an oil-tight joint. Fig. 15 shows the appearance of the weld around the rivet heads. Welding around the rivet heads by means of

the oxy-acetylene flame was tried, but was not found successful, because the heat from the flame when welding successive rivets caused the weld already made to crack.

Malleable-iron bosses are welded to sheet-steel tanks instead of

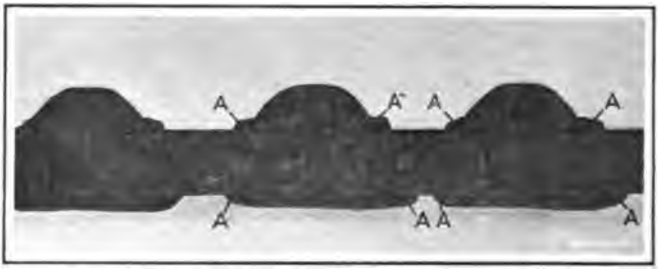


Fig. 14. Boiler Plate riveted together, showing Space between Rivets and Plate, and how Rivet is made Oil-tight by welding Head to Plate

being fastened by riveting. In this case, carbon electrodes with a soft metal feeding rod are used. The cast-iron heads, however, cannot be welded to the sheet-steel tanks, mainly because of the different expansions in the two metals when welding; hence, the cast-iron heads are riveted to the shells and the rivet heads

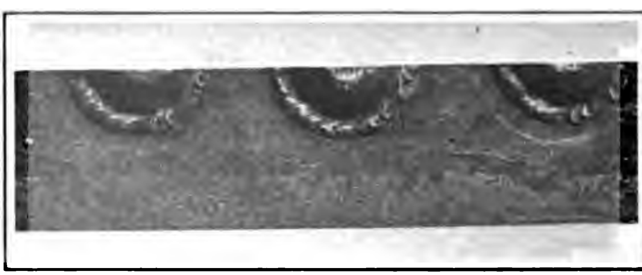


Fig. 15. Appearance of Welds when Rivet Heads have been welded to Plate by Electric Arc Welding

welded as previously explained. Small corrugated tanks have the sheet-steel shell cast directly into the cast-iron flange.

The work is always the positive electrode, and the carbon or metallic electrode, the negative terminal. The positive electrode may be clamped to the work anywhere.

Data for Butt-Welding of Sheet Metal by the Electric Arc (Metallic Electrode)

Thickness of Metal, Inches	Diameter of Electrode, Inches	Speed per Hour, Feet	Amperes			Mean K.W. at 60 Volts	Mean K.W. at 70 per cent Efficiency	Electrode Used per Hour, Pounds	Cost of Power per Hour, Cents	Cost of Electrode per Hour, Cents	Total Cost per Hour, Cents *	Total Cost per Foot, Cents
			Low	Mean	High							
$\frac{1}{16}$	$\frac{1}{16}$	20.0	25	30	40	1.8	2.6	0.9	7.8	4.5	42.3	2.12
$\frac{1}{8}$	$\frac{1}{8}$	16.0	30	50	75	3.0	4.3	1.4	12.9	7.0	49.9	3.12
$\frac{1}{4}$	$\frac{1}{8}$ or $\frac{3}{16}$	10.0	70	100	125	6.0	8.6	3.1	25.8	15.5	71.3	7.13
$\frac{3}{8}$	$\frac{3}{16}$ or $\frac{1}{4}$	6.5	100	125	150	7.5	10.7	3.6	32.1	18.0	80.1	12.30
$\frac{1}{2}$	$\frac{1}{4}$	4.3	120	140	175	8.4	12.0	3.8	36.0	19.0	85.0	19.80
$\frac{5}{8}$	$\frac{1}{4}$	2.8	125	155	195	9.3	13.4	3.4	40.2	17.0	87.6	31.30
$\frac{3}{4}$	$\frac{1}{4}$	2.0	125	160	200	9.6	13.8	2.4	41.4	12.0	83.4	41.70
1	$\frac{1}{4}$	1.4	125	160	200	9.6	13.8	2.7	41.4	13.5	85.9	61.30

* Labor estimated at 30 cents per hour.

The general problems met with in electric arc welding are dealt with in Chapter VIII and apply, of course, to tank welding, as well as to other kinds of welding; hence, there is no need at this point to dwell upon these questions. The only points that might be of particular interest in this connection are the strength of the seams as compared with riveted joints and the cost of the welding, including the cost of current, welding material, and labor. In addition, the character of the welds made, as shown by photomicrographs, will be briefly dealt with in the following paragraphs.

Strength of Seams. — The arc-welded butt-joint, if properly made, has been found to be quite as strong as a lap-welded single-riveted joint. A lap-welded joint will be found to be stronger than a single-riveted lap-joint, and as the joints required for the transformer tanks are sufficiently strong when single-riveted, it follows that either butt-welded or lap-welded seams made by the electric arc are amply strong.

Fig. 16. Photomicrograph of Steel Tubing welded to Boiler Plate, taken at A in Fig. 22

Data for Sheet-metal Welding. — The table on page 279 gives the thickness of metal, diameter of electrode used, speed per hour, current required, and cost of power and electrode for sheet-metal welding. This table is based on carefully made records, and represents actual experience in manufacturing work. Power is assumed to be available at 3 cents per kilowatt-hour, and the electrode metal is assumed to cost 5 cents per pound. The total cost per hour includes labor cost at the rate of 30 cents per hour, but, at the present time, with the high rate of wages, this is not sufficient. A rate of at least 50 cents should be assumed.

Fig. 17. Photomicrograph of Steel Tubing welded to Boiler Plate, taken at B in Fig. 22

Photomicrographs of Arc-welded Joints. — Figs. 16 to 22 inclusive show the appearance of arc-welded joints as seen under the microscope. At the left in Fig. 22 is shown a diagrammatical illustration of a tube welded to a flat plate. The photomicrograph in Fig. 16 is taken at *A*. The figures 1, 2, and 3, in Fig. 22, correspond to the figures 1, 2, and 3 in Fig. 16, the area indicated by 1 being the tubing; that indicated by 2 being the boiler plate; and that indicated by 3 being the weld, which is of Swedish iron. The black spot is a cavity at point *A* where the tube and the plate did not come together perfectly, there being a minute flaw or cavity at the edge of the plate. This cavity is not in the weld itself, and does not indicate any defect in the weld. In Fig. 17 is shown a photomicrograph of the same weld taken at *B*, where the figures 1, 2, and 3 indicate the tubing, the boiler plate, and the Swedish iron welding material, respectively, the same as in Fig. 16. The line between 1 and 2 shows the junction between the tubing and the plate. The homogeneity of

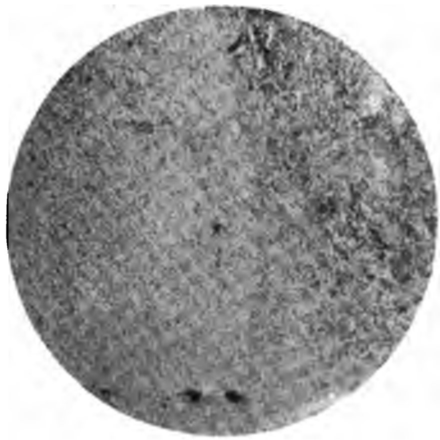


Fig. 18. Photomicrograph of Rivet Head welded to Boiler Plate

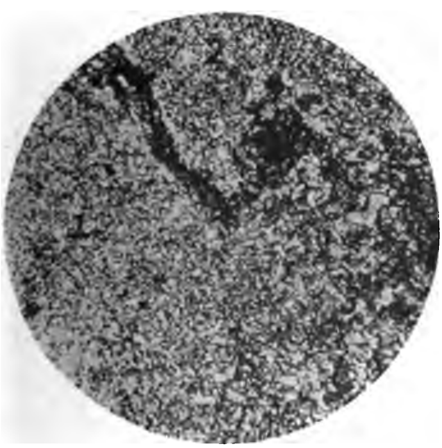


Fig. 19. Enlarged View, showing Center of Weld in Fig. 17

the weld is quite apparent. Fig. 18 shows a photomicrograph of a weld between a rivet head and boiler plate, the welds themselves being shown in Figs. 14 and 15. The line of the weld runs vertically through the center of the photomicrograph between two areas that are slightly different in color. Fig. 19 shows the central part of the same weld as illustrated in Fig. 17, but at a higher magnification. Fig. 20 shows a photomicrograph of the joint at *E* between plate *C* and the welding material in the case of two boiler plates being welded together, as shown to the right in Fig. 22. The figure 1 is Swedish iron welding material, and 2 is the boiler plate. Fig. 21 illustrates the joint at *F* and is made with a slightly higher magnification. Here 1 is again the Swedish iron welding material and 2, the boiler plate.

Fig. 20. Photomicrograph showing Joint between Welding Metal and Boiler Plate

Fig. 21. Another Photomicrograph showing Joint between Welding Metal and Plate

Cutting Metal by the Arc or Oxy-hydrogen Flame. — The ends of the shells for the transformer tanks must often be trimmed, and this trimming or cutting of the metal is performed by the oxy-hydrogen flame rather than by the electric arc, on

account of the clean, smooth cut that the hydrogen flame will produce. While the arc could be used for this purpose, it has not been found advantageous, on account of the length of time that would be required in the effort to obtain a smooth cut, and, furthermore, the result would not be as satisfactory as that obtained by the hydrogen flame; hence, in the manufacture of transformer tanks, it has been found that there is a distinct field for the electric arc and for the gas flame. The electric arc is used for all welding operations, while the gas flame is used for the trimming or cutting operations. In welding,

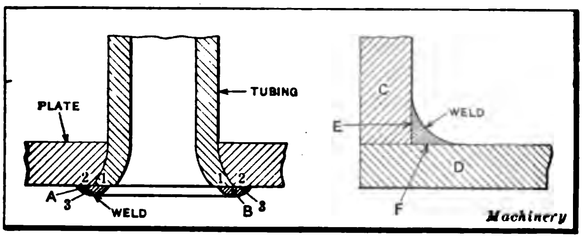


Fig. 22. Diagrammatical View of Welds illustrated by Photomicrographs

the electric arc method has also one other great advantage over the oxy-acetylene method, in that when using the metallic electrode, the position of the seam or weld is of no importance. It may be overhead, vertical, or horizontal. The weld can be properly made in every case. The metal from the feeding rod is actually carried over with considerable force by the arc, and is driven against the welded surfaces, even when the electrode is held underneath the seam to be welded. Work of this kind, of course, cannot be accomplished by the oxy-acetylene flame, as in that case the molten metal from the feeding rod drops, by gravity, into the weld, and, hence, the weld must always be in a horizontal or nearly horizontal position.

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